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AN 11-YEAR SUMMARY OF FINE AGGREGATE ACCEPTANCE TESTS 1951-1961

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AN 11-YEAR SUMMARY OF FINE AGGREGATE ACCEPTANCE TESTS, 1951-1961

Phase 2
of
Physical Research Project No. 9

"Acceptability Tests for Fine Aggregates"

A Report by
New York State Department of Public Works
in cooperation with
U. S. Department of Commerce
Bureau of Public Roads

Bureau of Physical Research

August, 1962

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ABSTRACT

This report constitutes a review and summary of the results of acceptance tests performed on samples of concrete fine aggregate submitted to the Bureau of Materials of the New York State Department of Public Works during the eleven year period from 1951-1961. It is intended, primarily, to provide a basis for the planning of subsequent phases of Physical Research Project No. 9.

The report is divided into two sections, a discussion of the effect that the various test procedures have had on fine aggregate acceptance, and a description of fine aggregate sources in New York State in terms of the results of these acceptance tests. Because the statements that are made in the section on fine aggregate sources are based on observed rather than experimental data, they should not necessarily be considered conclusive (pages 15-22 and Conclusion 9).

A convenient summary is included at the end should the reader not wish to labor through the considerable detail of the report body.

The following conclusions have been drawn from this study of laboratory data:

1. Considering New York State as a whole, the magnesium sulfate salt soundness test has been, by far, the quality test most frequently associated with fine aggregate rejection.

2. The sodium sulfate salt soundness test as performed and used in New York State since August, 1959 is virtually ineffective as a means of establishing either the acceptability of individual fine aggregate submittals or the general suitability of fine aggregate deposits by New York standards of acceptance.

3. Adherence to a maximum allowable loss of 15 percent in the magnesium sulfate salt soundness test as suggested by ASTM Designation C 33-61T in lieu of the 22 percent currently specified by New York would have resulted in a serious reduction in the number of acceptable submittals (33 percent) and the number of acceptable sources (41 percent). This reduction would have been felt primarily in the western counties.

4. Organic contamination of fine aggregates has been only a very minor cause for fine aggregate rejection in New York.

5. Considering New York State as a whole, the largest single factor in the rejection of initial submittals of fine aggregate has been non-compliance with gradational requirements.

6. An adjustment of the New York gradational requirements to those of the ASTM or the AASHO would have resulted in 69.0 and 63.2 percent fewer rejections, respectively, for initial submittals.

7. The utilization of only types "a" and "b" fine aggregate in Districts 6 and 9 has limited the number of acceptable submittals from these districts to about one-fifth and the number of suitable deposits to about one-third of what they would have been had the use of type "c" also been permitted.

8. The quartz and feldspar requirement of the rational analysis has been the primary factor in downgrading fine aggregates from types "a" and "b" and the primary factor in rejection in Districts 6 and 9, followed by the magnesium sulfate salt soundness test.

9. None of the broad systems of fine aggregate deposit classification used in the Phase 1 report appear to define the properties of materials sufficiently to be of value as a means of indexing engineering experience with these aggregates.

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INTRODUCTION

Physical Research Project No. 9 is one of several projects of a continuing nature that have been undertaken by the Bureau of Physical Research. These projects are directed toward improving our understanding of those materials that are in wide and continuous use by the Department in public works construction. Project No. 9 is concerned with fine aggregate; in particular, fine aggregate that is of a quality and gradation suitable for use in portland cement concrete. Because of the abundance in New York State of natural deposits of suitable material, this source is by far the greatest supplier of concrete fine aggregate.

The standard that is presently used by the State for measuring the acceptability of fine aggregate was established with the issuance of the Public Works Specifications of January 2, 1951 (1)*. The present specification, therefore, has been in effect for a period of eleven complete years. This report consists of a summary of tests performed in the laboratory of the Bureau of Materials on concrete fine aggregates submitted during this eleven year period, 1951 through 1961.

PURPOSE AND SCOPE

In summarizing and reviewing this considerable accumulation of acceptance test results, certain guides have been used. These guides are listed on the next page as general statements of purpose.

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* Numbers underlined in parentheses refer to the references cited at the end of this report.

1. To review the status of fine aggregate acceptance procedures in New York and to study the influence that these procedures have had in classifying and in determining the acceptability of concrete sands,

2. To examine the effect of certain hypothetical specification changes, and

3. To further describe the nature of New York fine aggregate sources, which description was begun with the Phase 1 report (2).

The information that is presented has been summarized from complete sets of test results accumulated, for the most part, during the eleven year period from 1951 through 1961, and represents approximately 935 submittals of fine aggregate from more than 220 individual sources, most of which are located within the State of New York. Supplemental submittals for the purpose of re-evaluation or confirmation of a single test result are not included. Retesting for gradational compliance constitutes the majority of these supplementary submittals. The numerous figures and tables referred to in this report are grouped in the Appendix in the order in which they are discussed in the text.

SUMMARY OF FINE AGGREGATE MATERIAL SPECIFICATIONS

The current fine aggregate material specification of the New York State Department of Public Works (3) consists of requirements for both quality and gradation. Under the former are included some general qualitative statements regarding hardness, durability, soundness, coatings and deleterious materials; quantitative performance levels for various indirect soundness tests including the magnesium and sodium sulfate salt soundness tests and the rational analysis; and limitations on deleterious organic impurities.

The sulfate salt soundness test and the rational analysis provide information that is helpful in juding the soundness of aggregates subject to weathering. Both sulfate salt tests attempt to simulate the growth of ice crystals in the pores of aggregate particles by subjecting them to a predetermined number of cycles of alternate soaking and drying in a

saturated solution of the salt. The commonly accepted explanation of the mechanism that causes aggregate disruption in the salt soundness test is as follows (4). During the first period of immersion, the aggregate pores become partially filled with the saturated salt solution. Upon drying in the oven, the anhydrous form of the salt is left behind. The second immersion results in the hydration of these salts and a corresponding increase in their volume which causes a pressure to be exerted against the pore walls of the aggregate. Subsequent drying and immersions may increase the volume of salt in the pores and repeat the stress condition caused by hydration.

Performance in this test is measured by the breakage that occurs within a 100-gram sample of each of the sizes of the fine aggregate series when subjected to such a test. The absolute breakage loss of each size is then weighed according to the gradation of the aggregate sample and the summed value of these weighed losses is reported as the loss for the entire sample. The procedure for performing these tests is essentially the same as ASTM Designation C 88-61T, Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (5).

The rational analysis, which is unique to New York State, is a quantitative determination of the chemical constituents of an aggregate sample. The constituents determined by this procedure are total quartz and feldspar, calcium carbonate, magnesium carbonate, metalic oxides of the form R_2O_3, and "kaolin". Two of these constituents, total quartz and feldspar and "kaolin" are limited by specification.

The rational analysis was first used by the Department in about 1930 (7). It was adopted from an analytical technique prevalent at the time in the ceramic industry (10). The term "kaolin" was apparently then used interchangeably with "clay" and did not carry the restricted meaning now assigned it by the relatively young science of clay mineralogy. The term has continued in used to the present time in connection with the rational analysis of fine aggregate.

An explanation of the significance assigned to the rational analysis at the time of its adoption can be obtained from the published writings of the people then in the Department who were concerned with materials problems:

"The Rational Analysis ----- [shows] how the elements contained in [a chemical oxide analysis are] combined. The results of this Rational Analysis would show; (1) Kaolin (theoretically pure clay). This would also include the clay which had been consolidated to shale or metamorphosed to slate, and the clay in the argillaceous materials; (2) Quartz either free or contained in the argillaceous materials or sandstone; (3) Feldspar; (4) Calcium Carbonate and (5) Magnesium Carbonate" (10, p. 91).

"By means of the chemical and rational analysis, we are able to classify ----- sands (1) as quartz sands -----, (2) quartz and feldspar sands -----, (3) sands containing considerable limestone -----, and (4) sands containing considerable shale -----" (10, p. 94).

"The type of aggregates which disintegrate the most readily are the shales and slates or the aggregates in which clay or kaolin in some form is the chief component part" (10, p. 89).

"----- many supposed particles of sand [consist] of ----- minute grains (generally silica) held together by kaolin or clay which [has] some cementing value. When this kaolin or clay is broken up, miniature disintegration of the sand grains takes place. This seems to be the one way in which disintegration of sand particles and, hence of mortar, does occur. Therefore, the percentage of kaolin should be a minimum" (11, p. 182).

"The most desirable components in the sand as determined by our rational chemical analysis are the feldspar, quartz, limestone ----- and oxides of aluminum and iron (R_2O_3)" (11, p. 184).

"Many of our sands absorb ten times the amount of moisture that others will absorb. It is a well-known fact that sands high in silica [and] feldspar ----- will absorb practically no moisture. Sands, however, which contain such unsound elements as shale, argillaceous sandstone and limestone, chert, etc., are relatively soft elements and will absorb considerable moisture. When moisture is in the mortar and subjected to alternate freezing and thawing, disruptive forces

are doing work which causes first the symptom of scaling and then probably the desease of disintegration" (12, p. 563).

The colorimetric test is used to detect the presence of organic impurities in sand, some of which inhibit the strength development of the mortar, at least in its early age. If the organic content exceeds a certain level, as indicated by the color of a 3 percent solution of sodium hydroxide added to the sand, the sand must then be examined for its mortar making properties. This further examination consists of comparing the strength development of mortar made with the questionable sand with that of mortar of similar mix proportions and consistency made with a standard Ottawa sand. This procedure differs from that of ASTM Designation C 87-61T, Tentative Method of Test for Measuring Mortar-Making Properties of Fine Aggregate (5), in several respects the most important of which are: the use of standard Ottawa sand instead of a mixture of standard and graded Ottawa sand; the molding of strength specimens to constant proportions and consistency instead of constant water-cement ratio; and the use of both tensile and compressive strengths instead of just compressive strengths as a basis for comparison.

The limits of the New York fine aggregate specification are given in Table 1. It will be noticed that sands are classified by type depending upon their performance in the salt soundness tests and their chemical composition as determined by rational analysis. In general, a fine aggregate submittal is considered acceptable for exposed concrete if it meets the requirements of type "a", "b" or "c" (see footnote, p.11). A distinction is made in this report between acceptance tests, those actually used to determine acceptability in a given instance, and classification tests, those used to classify materials meeting the minimum requirements for acceptance. The salt soundness tests serve as acceptance tests as well as classification tests. With regard to concrete sand, the rational analysis serves generally as a classification test as there are no required levels for kaolin and total quartz and feldspar for type "c" sands (see footnote, p. 11).

A REVIEW OF FINE AGGREGATE ACCEPTANCE TESTS

The figures and tables that are presented and discussed in this portion of the report describe the effect that the existing New York specification has had on fine aggregate acceptance and classification during the eleven year period of its use, and predict the influence of certain hypothetical changes to this specification. The discussion concerns fine aggregates that are intended for use in portland cement concrete only and is divided into three parts: (1) an analysis of the physical tests that have resulted in fine aggregate rejection in New York as a whole, (2) an analysis of the tests that have resulted in fine aggregate rejection in Districts 6 and 9 where only types "a" and "b" have been considered acceptable, (see footnote, p. 11) and (3) an analysis of the process by which fine aggregates have been classified as type "a", "b" and "c".

TESTS THAT HAVE RESULTED IN FINE AGGREGATE REJECTION IN NEW YORK AS A WHOLE

In general, concrete fine aggregates are either accepted or rejected at the type "c" level on the basis of the quality of the material as measured by the sodium and magnesium sulfate salt soundness tests, on the basis of the extent and nature of organic impurities, and on the basis of grain size distribution. The first of these is related to the inherent nature of the aggregate material while the other two are determined to a greater extent by the production process. The following discussion is based on data from all submittals included in this study and assumes that the limit of acceptability is established at the minimum requirements for type "c" fine aggregate even though the practice in Districts 6 and 9 has been to accept only types "a" and "b" material (footnote, p. 11). Submittals from these two districts are considered separately in the next section of the report.

During the eleven year period under consideration, 303 samples of fine aggregate failed, on their initial submittal, to meet the minimum requirements for concrete sand (type "c"). Figure 1(a) shows the percentage of these samples that failed each of the four physical tests required for acceptance.

The rational analysis is not included here as it is used only to classify as type "a", type "b" or type "c" those sands meeting the minimum requirements for acceptance. It is, perhaps, noteworthy that 303 sample failures constitute nearly one-third of the total number of 933 submittals considered in this study. Comparison of Figure 1(a) with Table 2, however, shows that only 133 of these 303 failures (slightly more than 14 percent of the total number of submittals) were failures of aggregate quality, that is, sodium and/or magnesium sulfate soundness failures* the remainder being failures of gradation alone.

Of further interest in Figure 1(a) are the relative frequency of failures by sodium and magnesium sulfate soundness, the low percentage of samples failing because of organic impurities, and the large number of gradation failures. These subjects are discussed below in that order.

SOUNDNESS FAILURES - Since the sodium and magnesium sulfate soundness tests are presumed to function by the same mechanism (4), it should be expected that results from both tests performed on the same aggregates would correlate. Such a correlation is implied by AASHO Designation: M 6-51 (6) which specifies soundness in terms of a maximum loss by sodium sulfate but notes that, "In case it is desired to use magnesium sulfate, a weighted loss should be specified which experience has shown will give results corresponding to a loss of 10 percent when using sodium sulfate". If the two tests do correlate and if limits of acceptability are properly set, then a sand that fails one of the tests would be expected to fail the other. From Figure 1(a), this is obviously not the case in New York where there have been 2.7 times as many failures in the magnesium test as there have been in the sodium test during the eleven year period under consideration. Table 3 shows, further, that of these 133 soundness failures, only 15 (11.3 percent) failed both tests.

Since the beginning of 1951, the solution concentration in the sodium sulfate test has been altered four times, as

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* The five that failed because of deleterious organic impurities also failed because of unsoundness.

shown in Table 3. In order to determine whether the two tests have correlated with one another, each of these periods was studied independently. Scattergrams (Figures 2a-e) for each of these periods show no correlation with the exception of the period from 11/23/57 through 2/24/58 when the solution concentration was at its maximum of 1.195. The data for this period is plotted in Figure 2(c). A line of average relationship calculated by the least squares method shows that losses of 8, 9, and 10 percent in the sodium sulfate test corresponded more closely with the performance levels set for the magnesium sulfate test than did the levels of 6, 7 and 8 percent specified. As presently performed, however, (Figure 2e), the two tests do not correlate well.

A further look at Table 3 shows that between August 15, 1959 and January 1962, a period of 2½ years, during which the last adjustment in the sodium sulfate soundness test procedure has been in effect, only four submittals have failed to meet the minimum requirements of the test. Two of these four also failed the test with magnesium sulfate, leaving only two that were classed as unacceptable because of their performance in the sodium sulfate test alone. Of these remaining two, one was accepted for use as type "c" fine aggregate, presumably on the basis of the past performance of submittals from this same deposit. Thus, only one fine aggregate submittal was actually rejected in this 2½ year period because of its failure to perform satisfactorily in the sodium sulfate soundness test alone. In terms of aggregate sources classified by the average properties of samples taken during the eleven year period (Figure 3), only one of the deposits from which the 133 unacceptable submittals were taken would have to be reclassified as acceptable (type "a", "b" or "c") had the test with sodium sulfate not been in use. It appears, therefore, that the sodium sulfate soundness test as presently performed and interpreted in New York State is almost completely ineffective in establishing the acceptability of fine aggregate submittals (by New York standards) at the type "c" level or as a means of establishing the general suitability of fine aggregate deposits. This is not to say that it is a less precise indicator of material quality than the test with magnesium sulfate, but merely that with the existing limits on sodium and magnesium sulfate soundness, the losses in the test with sodium sulfate are usually sufficiently low that acceptability is governed by performance in the test with magnesium sulfate.

Figure 3 is a geographical plot of fine aggregate deposits classified as to type by the average value of acceptance test results from samples taken during the eleven year period. Figure 4 is a similar plot of these same deposits based on the average loss of samples in the magnesium sulfate soundness test. It has been suggested above that if the soundness test using sodium sulfate were to be discontinued as a part of the acceptance specification, the number of satisfactory submittals would remain essentially unchanged and the number of acceptable sources would be as represented by the red, yellow and black symbols in Figure 3.

ASTM Designation C 33-61T, Tentative Specifications for Concrete Aggregates (5), suggests 15 percent as the maximum allowable loss in the test with magnesium sulfate. If this were to be the only acceptance test in use and the level of acceptance were to be 15 percent instead of 22 percent, the consequences could be judged by considering what would have occurred under this same situation during the 1951-1961 period. The number of unacceptable submittals would have been 395 instead of 133 and, as a comparison of Figures 3 and 4 will show, the number of suitable sources 108 instead of 183. Figure 4 suggests that the effect of such a limit would have been felt predominantly in the western counties although to some extent in the Hudson and Mohawk Valleys. Thus, it can be seen that while New York's sodium sulfate test could probably be abandoned with little effect, a move from the 22 percent acceptance level now in use with the magnesium sulfate test to the 15 percent level suggested by ASTM Designation C 33-61T should involve serious consideration as it would substantially alter the number of producers able to meet the new requirement.

FAILURES BECAUSE OF ORGANIC IMPURITIES - Five submittals in the eleven year period failed both the colorimetric test for organic impurities and the supplemental strength test for mortar making properties. This number constitutes only 1.7 percent of the failures and 0.5 percent of the total number of submittals during this period. It can be concluded with certainty that the nature of the natural aggregate deposits in New York and the methods of processing these aggregates have been such as to practically preclude organic contamination as a major source of concern.

GRADATIONAL FAILURES - During the eleven year period examined in this report, 201 samples failed to meet the gradational requirements for concrete sand on their initial submittal (Figure 1). By year, the number varied between 11 and 32 percent of initial submittals with an eleven year average of 21.6 percent. The resampling and retesting that is performed by the Department is largely the result of the failure of initial and subsequent submittals to meet these gradational requirements. During the eleven year period, fine aggregate deposits were resampled for laboratory testing 99 times, 82 of which were for determination of gradational compliance after failure of the initial submittal.

Figure 5 is a graphical comparison of the New York specification with that recommended by the American Society for Testing and Materials (5a) and the American Association of State Highway Officials (5b). It can be seen that in each case the New York specification is included within the gradational limits of the other except for the #4 screen for both and the #8 screen for the ASTM specification. The ASTM specification carries the additional requirement that the fineness modulus be in the range 2.3 to 3.1 inclusive.

Figure 6 includes a graphical summary of the gradational violations occurring for initial submittals under the New York specification during the eleven year period (black bars). The most common violation has been an excess of material finer than the #14 screen. This has occurred nearly twice as often as the next most frequent violation. The #8 and the #28 screens, although part of the fineness modulus series, are not included in the New York specification. The data constituting each group of failures represented by the black bars in Figure 6 was examined for some recognizable pattern. Each failure type was found to be reasonably uniformly distributed throughout the State, that is, none were dominated by submittals from only one or two geographical areas.

The plain and the cross-hatched bars in Figure 6 represent the number of violations that would have occurred from these same submittals had the ASTM or AASHO specification, respectively, been in effect. These bars for the #4 and #8

screens have limited significance as they are associated with restrictions that fall within the range of acceptability of the New York specification and, therefore, are abnormally high because they represent requirements for which no particular effort was extended. For the #28 screen, the plain bars show the number of violations that might have occurred had their been a specification requirement for this size set at the ASTM level. For the #14, #48 and #100 screens, the plain and cross-hatched bars show the effect that an adjustment of the New York specification to either that of the ASTM or the AASHO would have had on the number of violations (a decrease of 69.0 and 63.2 percent respectively). A considerable decrease in the amount of resampling and retesting would be the practical significance of such action. The plain bars on the extreme right of the figure show the number of submittals that failed to meet the ASTM requirements for fineness modulus.

TESTS THAT HAVE RESULTED IN FINE AGGREGATE REJECTION IN DISTRICTS 6 AND 9

Figure 1(a) summarizes data collected on fine aggregates submitted from all parts of New York State as well as several from neighboring states and dredged sources. Figure 1(b), on the other hand, shows the same type of information summarized for Districts 6 and 9 alone where only fine aggregate types "a" and "b" are considered acceptable for use in portland cement concrete.* The rational analysis becomes an acceptance test in these districts as it is one of the means of distinguishing between type "b" and type "c" sands in the New York specification.

Of the 113 submittals from Districts 6 and 9 during the eleven year period, 101 (84.0 percent) were not acceptable (ie., types "a" or "b"). In terms of fine aggregate sources, as classified by the average properties of samples (Figure 3), there are only six acceptable deposits in the two districts, four of which are in Sullivan County in the Eastern part of

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* In this analysis, it is assumed that the acceptance of only types "a" and "b" sands in Districts 6 and 9 has prevailed through the entire eleven year period, even though both have recently dropped this requirement.

the region. Had the use of type "c" sands been permitted in this area (Figure 1c) the number of unacceptable submittals would have been only 49 (43.4 percent) and the number of suitable sources 19 (Figure 3). Thus, the use of type "c" sands in Districts 6 and 9 would have reduced the unacceptable submittals by about one-half and increased the number of suitable deposits by more than three times with a much more satisfactory distribution.

Of further interest in Figures 1(b) and 1(c) are the relative occurrence of failures by the magnesium and sodium sulfate soundness tests and the influence of the rational analysis, in particular the quartz and feldspar requirement, in causing the rejection of sands in those districts. Some of the data used in Figures 1(b) and 1(c) are presented in a different manner in parts (d) and (e) of Figure 7 so as to show the frequency of failure by individual tests and combinations of tests under the two conditions, exclusive of gradation and organic impurities. It may be noticed that the use of type "c" materials in these districts would have reduced the number of rejections because of quality by about 73%. In addition, no submittals failed because of performance in the sodium sulfate test alone (Figure 7d) nor would they had type "c" sands been acceptable in these districts (Figure 7e). Of considerable interest is the fact that 43.8 percent of the fine aggregate quality failures at the type "b" level (Figure 7d) occurred because of the rational analysis alone, while another 45.8 percent occurred because of the rational analysis in combination with other tests. The ineffectiveness of the sodium sulfate test is again emphasized and the strong influence of the rational analysis, particularly the quartz and feldspar requirement, in causing fine aggregate rejection in these districts is apparent. In this respect, the soundness test with magnesium sulfate is secondary to the requirement for quartz and feldspar.

TESTS THAT HAVE RESULTED IN DOWNGRADING OF FINE AGGREGATES

Having met the requirements of a type "c" material, a fine aggregate submittal is classified as either type "a", type "b" or type "c" based on its performance in the sodium and magnesium sulfate salt soundness tests and the rational

analysis. In practice, this classification system is put to use only in those districts specifying types "a" and "b" sands and in certain architectural applications requiring the use of white cement and a sand high in quartz and feldspar.

A breakdown of fine aggregate submittals by "type" and by year for the eleven year period under consideration is presented in Table 2. It can be seen that during this period, approximately 25 percent of these submittals were type "a" sands, 16 percent type "b" sands and 46 percent type "c" sands while only 14 percent failed to meet the minimum requirements of a type "c" sand. These proportions have remained reasonably constant from year to year.

Figure 3 presents a grouping of this same data by source location, the type designation of each source being based on the average properties of samples submitted over the eleven year period. The data presented in this manner shows approximately the same distribution of fine aggregate by type as does Table 3.

Figure 8 shows, separately, the percentage of submittals not meeting the various requirements of fine aggregate types "a" and "b". The same data presented differently in parts (a) and (b) of Figure 7 show the tests and combinations of tests causing downgrading at the different levels. Worthy of note is the significant role played by the quartz and feldspar requirement of the rational analysis in disqualifying sands for a type "a" or type "b" designation, a deficiency in quartz and feldspar being involved in 87.8 percent and 75.6 percent, respectively, of the downgradings. A deficiency in quartz and feldspar alone was responsible for 24.2 percent of the downgradings from type "a" and 36.4 percent of the downgradings from type "b"; and in combination with the magnesium sulfate soundness test, another 24.0 and 21.0 percent, respectively. The quartz and feldspar requirement of the rational analysis, therefore, appears to have been, by far, the principal agent in downgrading fine aggregate submittals, with the magnesium sulfate soundness test being secondary in this respect. The kaolin requirement of the rational analysis and the sodium sulfate soundness test have been only minor contributors to these downgradings.

The classification of fine aggregates by the magnesium sulfate soundness test alone during the eleven year period would have had practical significance in Districts 6 and 9 only. In these districts, the number of acceptable submittals would have been 59 rather than 12; and the number of suitable deposits 12 rather than 6.

ANALYSIS OF TEST ASSOCIATIONS

If all those submittals that failed to meet a particular test requirement for, say, type "a" sand over a given period of time were expressed as a decimal fraction of the total number of samples submitted over this same period, the resulting figure would represent the probability of randomly selecting a submittal from this period that failed to meet the type "a" requirement for the particular test. Using probabilities determined in this same manner for the other three tests and taking into consideration the various combinations of test failures that could occur, it would be possible to determine the probability of any combination of test failures occurring in this same randomly selected submittal. Such a determination would assume that passage or failure in any test or any combination of tests in no way influences passage or failure in any other, that is, that the tests at the performance levels considered (type "a" in this case) are completely independent of one another. For any given pair of tests, therefore, a comparison of the actual occurrence of failures in both with that predicted under the assumption of complete independence would give a qualitative measure of the degree to which the two tests are related (ie., overlap in function) at the particular performance level tested (ie., type "a"). The results of such an analysis are presented in Table 4.

The interpretation of Table 4 will be illustrated by making reference to the requirements for quartz and feldspar content and soundness in the test with magnesium sulfate for type "a" sands. A failure to meet the type "a" requirement for either quartz and feldspar or magnesium sulfate soundness will be associated with a failure to meet the other requirement more often than would be expected from chance associations alone. Thus, it can be seen that there is a

certain overlapping of function in the test procedures at the specified performance levels that are used to grade fine aggregates in New York. This overlapping is most apparent in the following pair of tests, (a) quartz and feldspar and magnesium sulfate soundness, (b) kaolin and magnesium sulfate soundness and, (c) sodium sulfate soundness and magnesium sulfate soundness.

A REVIEW OF FINE AGGREGATE SOURCE CHARACTERISTICS

An attempt was made to relate the fine aggregate properties measured in the laboratory to the broad systems of classification presented in the Phase 1 report (2). This was done in an effort to find an orderly method of indexing engineering experience with these aggregates. The aggregate properties considered were total quartz and feldspar, magnesium sulfate soundness, kaolin, distribution of unweighted magnesium sulfate soundness by particle size, and grain size distribution. Sodium sulfate soundness was not included because of the aforementioned variations that have taken place in the test procedure. The systems of deposit classification used in the Phase 1 report were physiographic province, pedological soil series name and depositional unit.

QUARTZ AND FELDSPAR CONTENT

The determination of total quartz and feldspar content of a sample in the laboratory is considered to be a highly accurate and reproducible measure of this property of an aggregate. Together, with a general knowledge of the bedrock geology of the State, it provides a useful clue to the rock-type origin of natural aggregate deposits.

VERSUS PHYSIOGRAPHIC PROVINCE - An attempt to relate this property to the physiographic regions of New York is represented by Figure 9 which is a plot of fine aggregate deposits based on the average quartz and feldspar content of samples collected over the eleven year period. It may be noted that the level of quartz and feldspar of fine aggregates in New York

is related in a general way to the physiography of the State, or more properly, to its bedrock geology. This relationship is more apparent for quartz and feldspar than for any of the other properties examined. In addition, Figure 9 supports the contention that glacially deposited materials in New York have for the most part not traveled great distances from their point of origin.

VERSUS SOIL SERIES NAME - All of the deposits that could be definitely associated with a pedological soil series having a granular parent material (Figure 10) were examined to determine the extent to which the soil series name defined the properties of materials taken from these deposits. Laboratory records extending back to 1931 were used for this prupose. Table 5 and Figure 11 summarize this information for the property of total quartz and feldspar content.

The first step was to examine the variation in mean quartz and feldspar content among all deposits associated with the same soil series name to determine whether or not such deposits could be considered as similar with regard to this property. The results of this examination are summarized in the first four columns of Table 5. In only five instances, when tested statistically at the 0.05 confidence level, did deposits with the same soil series association prove to be similar with regard to their mean quartz and feldspar content. Because of the small number of deposits or their limited geographical distribution no more than limited practical significance was given to any of the five cases.

The above may be interpreted as saying that examination of the available data indicates that for deposits of fine aggregate having the same soil series association, the level of quartz and feldspar may vary significantly from one deposit to another and, therefore, that the soil series name, while it may denote the quartz and feldspar characteristics of a group of deposits considered as a whole, it does not adequately describe any one deposit within the group.

The second step was to establish the quartz and feldspar characteristics of each of the soil series associations. The last two columns of Table 5 give the mean and standard deviation of total quartz and feldspar content for all samples

tested from deposits with the same soil series name. Figure 11 shows the same data arranged to illustrate the variation found in deposit means. In each, the soil series associations are arranged in ascending order of magnitude. Figure 11 is probably the more useful of the two presentations as it illustrates the range in deposit characteristics found within each soil type. From this figure, it may be concluded that the soil series name associated with a particular deposit does give an indication of the level of quartz and feldspar in the fine aggregate portion, although, the range in values is considerable for some soil types.

VERSUS DEPOSITIONAL UNIT - Within each physiographic region a qualitative examination was made of the relationship between total quartz and feldspar content and depositional unit. No relationship was apparent from the data examined.

MAGNESIUM SULFATE SOUNDNESS LOSS

VERSUS PHYSIOGRAPHIC PROVINCE - An attempt to relate this property to the physiographic regions of New York State is represented by Figure 4 which is analogous in its construction to Figures 3 and 9 already discussed. It can be seen that the level of $MgSO_4$ soundness bears only a poorly defined relationship to the physiography of the State indicating the presence of factors other than rock-type origin that significantly influence this property. This relationship for magnesium sulfate soundness is certainly not as well defined as that for quartz and feldspar.

Areas high in quartz and feldspar (Long Island, the Adirondacks and the Hudson Highlands) also show relatively good performance in the magnesium sulfate soundness test, suggesting an association between the two. The occurrence, however, of this same high performance in the soundness test from some deposits with relatively low levels of quartz and feldspar indicates that this property, although usually associated with good magnesium sulfate soundness, is not essential for it.

VERSUS SOIL SERIES NAME - The relationship between magnesium sulfate soundness and pedological soil series association was examined in the same manner as was that for total quartz and feldspar content. The results are summarized in Table 6 and Figure 12. In nine instances, when tested at the 0.05 confidence level, deposits with the same soil series association proved to be similar with regard to their mean magnesium sulfate soundness. In only two of these instances, however, that of the Howard and the Groton soils, were the number of deposits and the geographical distribution that they represented considered to be sufficient to give results of the statistical tests practical significance (see Figure 10). This would indicate that, for these two soil series associations, the among deposit mean soundness values shown in Figure 12 and the among deposit standard deviations calculated from pooled deposit variances* could be applied with reasonable certainty to any of the 18 deposits included within these groups. It also suggests that these values could be applied to any deposit associated with the Howard or Groton soil series although confirmation by additional sampling would certainly be advisable. Even when the Howard and Groton soil series are considered, the results of this analysis, when viewed as a whole, do not support the premise that the average magnesium sulfate soundness of deposits with the same soil series association adequately describe any one deposit within the group.

The second step, as before, was to establish the magnesium sulfate soundness characteristics of each of the soil series associations. This information is presented in the last two columns of Table 6 and in Figure 12. A comparison of Figures 11 and 12 indicates that the soil series association is a less precise indicator of magnesium sulfate soundness than of quartz and feldspar content, that is, the among deposit variations in soundness appear to be greater than those for quartz and feldspar. It has also been noticed in examining the data that, as a rule, within deposit variations of magnesium sulfate soundness are greater than within deposit variations of quartz and feldspar.

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* See any standard statistical text for the method of pooling variances.

VERSUS DEPOSITIONAL UNIT - Within each physiographic region, a qualitative examination was made of the relationship between magnesium sulfate soundness and depositional unit. No relationship was apparent from the data examined.

KAOLIN CONTENT

VERSUS PHYSIOGRAPHIC PROVINCE - An attempt to relate this property to the physiographic regions of New York State is represented by Figure 13. It can be seen that kaolin bears a poorly defined overall relationship to the physiography of the State. This relationship for kaolin, although not as vague as that for magnesium sulfate soundness, is not as well defined as it is for quartz and feldspar. There are, however, certain areas of the State that are worthy of note. Long Island deposits are conspicuous for their consistently low levels of kaolin, high levels of quartz and feldspar and good magnesium sulfate soundness. The Adirondacks, for the most part follow this same pattern. The pattern in the counties of western New York is interesting in that, with only two exceptions, no deposits are found in the Allegheny Plateau with average kaolin contents below 4 percent, while those of the Lake Ontario Plain are almost dominated by such deposits.

VERSUS SOIL SERIES NAME - The relationship between kaolin and pedological soil series name was examined in the same manner as done previously for quartz and feldspar and magnesium sulfate soundness. The results are presented in a similar manner in Table 7 and Figure 14. Only for the deposits associated with the Howard soil series were the number and the geographical distribution considered sufficient to give practical significance to the similarities found among deposits of the same soil series association. The among deposit mean given for the Howard association in Figure 14 and a pooled deposit variance* may, therefore, be used to describe the characteristics of any of the seven deposits associated with the Howard soil series name.

A comparison of Figures 11 and 14 indicates that the soil series association is a less precise indicator of percent

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* See note, p. 18

kaolin than of quartz and feldspar content, that is, the among deposit variations in kaolin appear to be greater than those for quartz and feldspar. It has also been noticed in examining the data that, as a rule, within deposit variations in kaolin are greater than within deposit variations in quartz and feldspar.

VERSUS DEPOSITIONAL UNIT - With each physiographic region, a qualitative examination was made of the relationship between kaolin and depositional unit. No relationship was apparent from the data.

DISTRIBUTION OF UNWEIGHTED SOUNDNESS LOSSES BY PARTICLE SIZE

By plotting the unweighted soundness loss of each of the individual particle size ranges of a fine aggregate sample and connecting these points by straight lines, a "curve" may be developed that is characteristic of the performance of that particular aggregate in the salt soundness test and that is unrelated to its gradation. An attempt was made to relate this "loss-particle size" curve to the geologic characteristics of the deposit from which the material was taken. For this purpose, the results of magnesium sulfate soundness tests were used. The geologic characteristics considered were depositional unit and physiographic region.

As a first step, variations in the "loss-particle size" curve within individual deposits were examined to determine whether they were sufficiently low to permit comparisons among deposits. All deposits listed in the Phase 1 report (2) from which more than one sample was submitted during the period 1951-1960 were examined, with the exception of those deposits located on Long Island. This included a total of 79 deposits. A systematic procedure for judging the agreement of test results on samples from the same deposit was established. Agreement among soundness losses for any particular particle size was said to be good if the losses of individual samples fell within the range of 0 to 4 percent; fair if within the range of greater than 4 to 8 percent; poor if within the range of greater than 8 to 12 percent and very poor if greater than 12 percent. The results of this examination are presented in Table 8 which shows the number of deposits falling into each category for each particle size range.

From the appraisal of within deposit variations in soundness for each aggregate particle size, an evaluation of the overall agreement within each deposit was made. Accordingly, deposits were rated as good, fair to good, fair, poor to fair, poor, very poor to poor and very poor. Typical examples of deposits falling into these various classifications are presented in Figure 15 together with the total number of deposits so classified. It was considered that only in deposits rated as fair or better was the agreement among soundness test results sufficiently good to allow the definition of a characteristic "loss-particle size" curve for the deposit. Since only 22 of the 79 deposits studied (approximately 28 percent) were so rated, it was decided not to attempt any systematic comparison of this characteristic among the various deposits.

It is reasonable to expect that "loss-particle size" curves determined under the same conditions of testing would reflect the characteristics of the material being tested and that within deposit variations in such curves, therefore, would reflect true variations in materials from the same deposit. It is thought, however, that such broad geologic classifications as landform and physiographic province are not sufficiently precise to define material characteristics as specific as those illustrated by a test procedure such as the salt soundness test. Even though no systematic examination was made of variations among deposits, a random inspection of deposits located within the same physiographic province and occurring in a similar depositional environment confirmed this last statement. Similarities could, however, be observed among deposits located within a limited geographic area that presumably had a common geologic history.

The apparent lack of uniformity in the soundness of fine aggregate samples taken from the same deposit can probably be attributed to several causes: natural within deposit variations, sampling and testing variations, and the fact that lab records do not always indicate the exact deposit from which a sample was taken even though the correct producer may be recorded. Some idea of the influence of testing variations can be obtained by referring to the bottom two rows of Table 8 which classify the variation observed in repeat tests performed on samples of the same material in the laboratory.

GRADATION

Attempts to correlate the gradation of fine aggregate submittals with the various systems of deposit classification were unsuccessful with the exception of those located on Long Island. This is undoubtedly due to the fact that the gradation of the processed sand, in most cases, bears little relation to its natural gradation. Fine aggregate submittals from Long Island, however, were consistently found to have an abundance of material finer than the #14 screen. Of 79 submittals examined from this area, ten were found to be unacceptable for this reason. The severity of this situation is undoubtedly greater than that indicated by these ten unacceptable submittals as a considerable amount of preliminary testing is carried out by District 10 personnel before samples are submitted to the Bureau of Materials' laboratory in Albany.

SUMMARY AND INTERPRETATION

SULFATE SALT SOUNDNESS TESTS

The tests with sodium sulfate and magnesium sulfate salts together with the determination of organic impurities are the means by which acceptable fine aggregate quality is determined in New York State. The salt soundness tests are also used with the rational analysis in classifying acceptable fine aggregates as type "a", type "b" or type "c", but this only has practical significance in Districts 6 and 9* where types "a" and "b" are used in exposed concrete to the exclusion of type "c". As the two salt soundness tests are presumed to function by the same mechanism, the need for utilizing both is questionable.

An examination of the records has shown that during the eleven year period from 1951 through 1961, the test with sodium sulfate has alone accounted for only 19 percent of the fine aggregate failures as compared to 70 percent for the test with magnesium sulfate alone. During the last 2½ years, since the last procedural adjustment, the test with sodium sulfate has been almost completely ineffective, accounting alone for

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* See note on page 11

only two (four percent) of the fine aggregate failures during this period. In Districts 6 and 9, it has alone accounted for no failures during the eleven year period. Thus, the test with magnesium sulfate has been, by far, the more effective of the two in establishing the suitability of fine aggregates by New York acceptance standards, almost to the complete exclusion of the other as it is presently performed. The test with magnesium sulfate has also played an important role in grading fine aggregates, second only to that of the quartz and feldspar requirement of the rational analysis. The high degree of association found between the two salt soundness tests at the acceptance levels specified (Table 4) adds further support to the thought that they are duplicating one another in their function. This is particularly true for materials failing to meet type "c" requirements.

The foregoing remarks suggest that, at least for the present, primary emphasis should be placed on the test using magnesium sulfate and that the test with sodium sulfate should either be re-evaluated as to its procedure and specified limit, or dropped entirely. Elimination of this test would decrease the soundness testing work load for fine aggregates by two-thirds or increase the capacity for performing tests with magnesium sulfate fourfold. It is curious to note that ASTM Designation C 33-61T specifies a maximum allowable loss of 10 percent after five cycles of the sodium sulfate test, yet New York requires better performance (maximum loss of 8 percent) at twice the number of cycles (10) and, even then, hardly ever rejects a material because of its performance in this test.

It is further pointed out by this report that adoption of 15 percent as the maximum allowable loss for the test with magnesium sulfate in accordance with ASTM Designation C 33-61T, if considered at all, should only follow very careful consideration as it would substantially influence the number of producers able to meet the new specification.

Although none of the systems of deposit classification was found to adequately define the soundness of fine aggregate samples, deposits located in the Adirondack area, in the Hudson Highlands and on Long Island have produced materials that consistently give losses less than 15 percent in the test with magnesium sulfate.

RATIONAL ANALYSIS

The requirements of the rational analysis for total quartz and feldspar and for kaolin are used only for the purpose of classifying fine aggregates meeting the minimum soundness requirements for type "c" material. As types "a", "b", and "c" are all generally acceptable for use in concrete the presence in the specification of the rational analysis is superfluous except in Districts 6 and 9 where they become acceptance tests and for an occasional architectural application requiring a high percentage of quartz.

In effect, the rational analysis serves as another indirect soundness test. Sand with high percentages of quartz and feldspar (greater than 80 percent) are generally found to perform well in the magnesium sulfate soundness test, at least those of predominately crystalline origin. Service records in Maine (8) show that concrete structures made with granite aggregates are most durable in this climate. Further support is given by the analysis of test associations (Table 4) which shows that sands failing both the type "a" and type "b" requirements for quartz and feldspar also fail these same requirements for magnesium sulfate soundness more often than chance would allow.

The limitation on kaolin is presumably intended to set apart materials such as argillacious limestones and sandstones, and shales that contain enough clay minerals that they are relatively soft and non-durable. It must be somewhat effective in this as levels of kaolin are comparatively low in most areas dominated by sands of crystalline origin and comparatively high in areas where shale is a common constituent of natural aggregate. Accordingly, Table 4 shows a significantly high degree of association between kaolin and magnesium sulfate soundness for submittals failing the type "a" and type "b" requirements and a similar association between the occurrence of high kaolin and low quartz and feldspar content for submittals failing the type "a" requirements.

The requirement of the rational analysis for quartz and feldspar has been the principal agent in downgrading fine aggregates and, therefore, in rejecting fine aggregates in Districts 6 and 9. As such a requirement eliminates broad

groups of materials that have been observed to be satisfactory for use in concrete, some of which could occur in Districts 6 and 9, it is suggested that either the practice of using only types "a" and "b" fine aggregates in these districts should be carefully reconsidered or the significance of the quartz and feldspar requirement should be thoroughly examined in terms of the nature of the available aggregate materials in these Districts. This is particularly important in view of the severe limitations which the use of only type "a" and type "b" fine aggregates has imposed on the number of acceptable sources in this area.

The requirement of the rational analysis for kaolin has been comparatively ineffective in resulting in either the downgrading of fine aggregates in the State as a whole or their rejection in Districts 6 and 9. This has been largely because of its frequent association with failures by other tests. It is felt, however, that there is merit to a test procedure that evaluates the presence of clay minerals in a concrete aggregate. The presence of clay minerals will influence such properties as strength and porosity, both of which are important in determining durability. It is therefore suggested that an effort to determine the true significance of the quantity defined as "kaolin" by the rational analysis procedure would be a worthwhile endeavor.

Except for the fairly good relationship between quartz and feldspar content and physiographic province, and quartz and feldspar and soil series association, the various systems of deposit classification are not sufficiently precise to adequately define the rational analysis of fine aggregate deposits.

ORGANIC IMPURITIES

The review of fine aggregate acceptance records shows that contamination by deleterious organic substances has been no problem during the past eleven years. The colorimetric test for organic impurities is one that is quick and simple to perform and there is no reason to consider its discontinuance.

A limited series of tests recently performed in the laboratory of the National Sand and Gravel Association (9) involved a comparison of two samples of sand from the same source, one with a harmful organic content and the other free from harmful organic matter. The sand with harmful organic content showed serious deficiencies in mortar strength at early ages but, they disappeared by 28 days at which time the sands showed equal mortar strengths. Tests for setting time and rate of hardening showed about a five hour delay caused by the presence of the organic matter. These results suggest that the rejection of sands which show color in the organic matter test and fail the supplemental test for mortar making properties at 7 days might be tempered depending upon the requirement for concrete structures, of which they are a part, to sustain design loads during their early life.

GRADATION

In most instances, fine aggregate submittals that are not properly graded to the New York specification are the result of normal sampling variations or causes for which fairly easy adjustment can be made, in the processing plant. The burden to the Department, then, of the one out of every four to five initial submittals that fail because of improper gradation, is largely one of resampling and retesting until compliance is obtained. It has been shown that broadening of the comparatively narrow limits of the New York specification would eliminate much of this additional work. If such action could be taken without a sacrifice in concrete quality, it would seem worthwhile to do so.

Considered to be of equal importance, however, are controls that would insure that a supplier maintain a reasonable gradation consistency for a particular job once he has selected the area of the specification in which he intends to produce.

SYSTEMS OF DEPOSIT CLASSIFICATION

None of the systems of deposit classification, either individually or together offer a means of adequately defining the properties of fine aggregates. This is not to say that they are of no value as Figures 9 and 11, for instance, will suggest that they do have some merit. But, for the stated purpose of providing a system by which engineering experiences may be catalogued, it is felt that they do not adequately reflect all the factors that have determined the engineering properties of natural aggregates in New York. It is suggested that a detailed study and mapping of the glacial geology of the State may offer a valuable and more precise means of classifying deposits. Such a program has begun and is essentially completed in the western part of the State.

CONCLUSIONS

Based on the analysis and discussion of fine aggregate acceptance tests and fine aggregate deposits, the following major conclusions, presented in the order of their development, appear to be justified. They are, of course, limited in scope to the period covered by the laboratory data that was examined.

1. Considering New York State as a whole, the magnesium sulfate salt soundness test has been, by far, the quality test most frequently associated with fine aggregate rejection.

2. The sodium sulfate salt soundness test as performed and used in New York State since August, 1959 is virtually ineffective as a means of establishing either the acceptability of individual fine aggregate submittals or the general suitability of fine aggregate deposits by New York standards of acceptance.

3. Adherence to a maximum allowable loss of 15 percent in the magnesium sulfate salt soundness test as suggested by ASTM Designation C 33-61T in lieu of the 22 percent currently specified by New York would have resulted in a serious reduction in the number of acceptable submittals (33 percent) and the number of acceptable sources (41 percent). This reduction would have been felt primarily in the western counties.

4. Organic contamination of fine aggregates has been only a very minor cause for fine aggregate rejection in New York.

5. Considering New York State as a whole, the largest single factor in the rejection of initial submittals of fine aggregate has been non-compliance with gradational requirements.

6. An adjustment of the New York gradational requirements to those of the ASTM or the AASHO would have resulted in 69.0 and 63.2 percent fewer rejections, respectively, for initial submittals.

7. The utilization of only types "a" and "b" fine aggregate in Districts 6 and 9 has limited the number of acceptable submittals from these districts to about one-fifth and the number of suitable deposits to about one-third of what they would have been had the use of type "c" also been permitted.

8. The quartz and feldspar requirement of the rational analysis has been the primary factor in downgrading fine aggregates from types "a" and "b" and the primary factor in rejection in Districts 6 and 9, followed by the magnesium sulfate salt soundness test.

9. None of the broad systems of fine aggregate deposit classification used in the Phase 1 report appear to define the properties of materials sufficiently to be of value as a means of indexing engineering experience with these aggregates.

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3. State of New York, Department of Public Works, Division of Construction, Public Works Specifications dated January 2, 1957.

4. Sweet, Harold S., "Physical and Chemical Tests of Mineral Aggregates and Their Significance," ASTM, STP No. 83, 1948.

5. American Society for Testing and Materials, Standards, Part 4, (1961).

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7. Paul, Ira, "Magnesium Sulfate Accelerated Soundness Test on Concrete Aggregate," Proceedings, HRB, Part I, 1932.

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9. National Sand and Gravel Association, Technical Information Letter No. 157, September 15, 1959.

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11. Lawton, S. C., "Progress in Determining Suitability of Concrete Pavement Aggregates," Proceedings, Association of Highway Officials of the North Atlantic States, 1932.

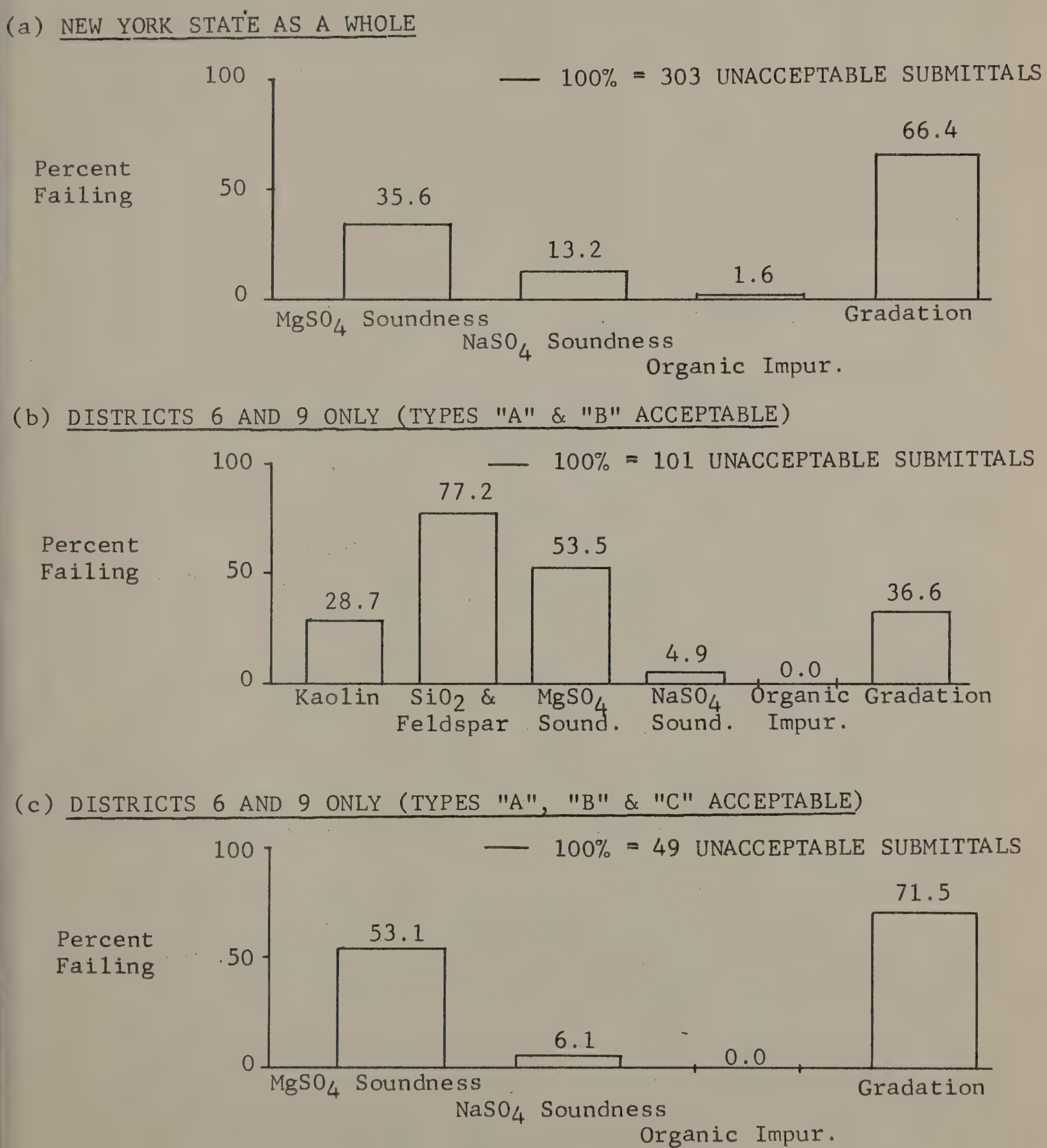
12. Lawton, E. C., "Durability of Concrete Pavement - Experiences in New York State," Journal, A. C. I., June 1939.

APPENDIX

Figures 1 Thru 15

Tables 1 Thru 8

FIGURE 1 PERCENTAGE OF UNACCEPTABLE SUBMITTALS FAILING VARIOUS TESTS



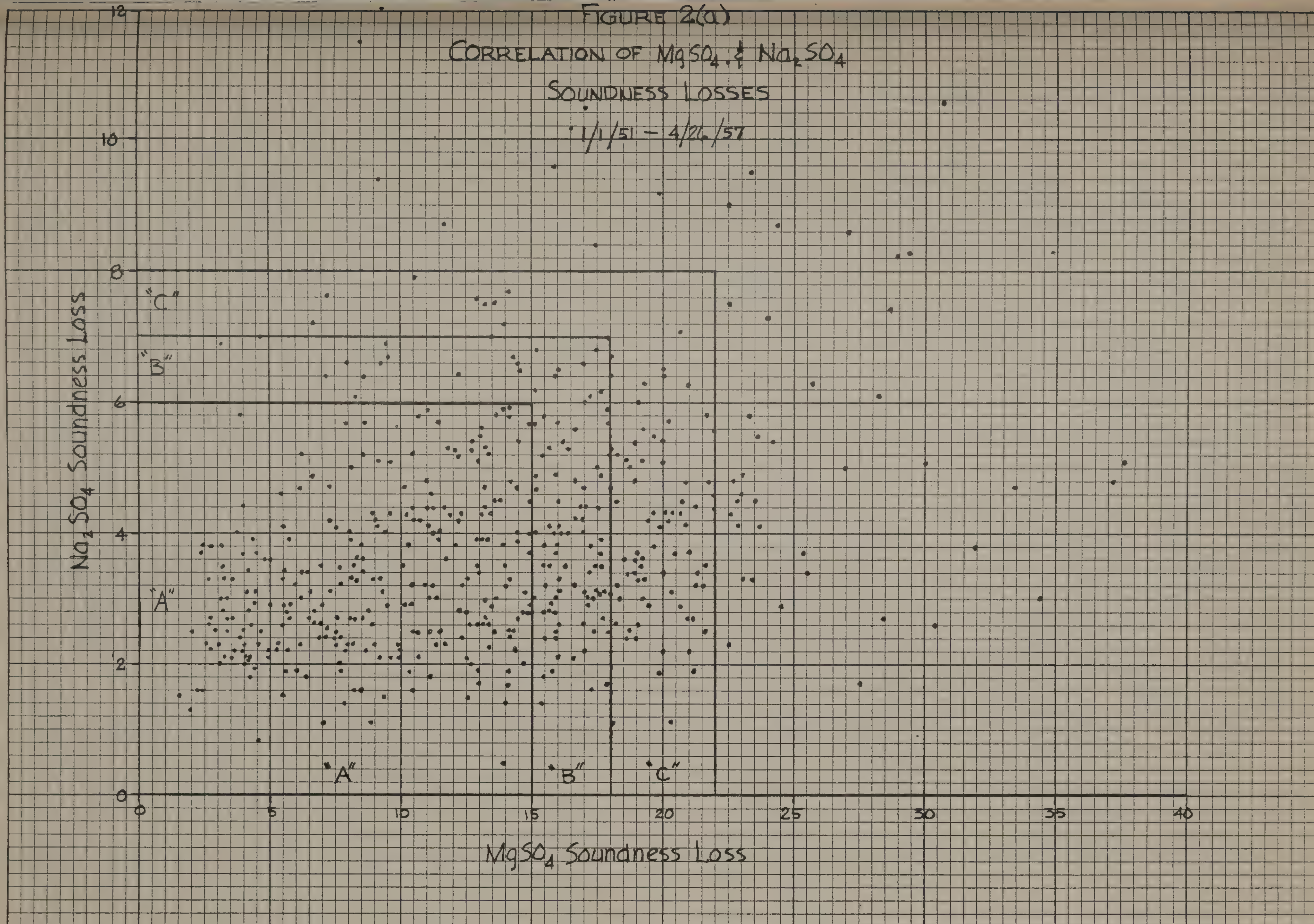
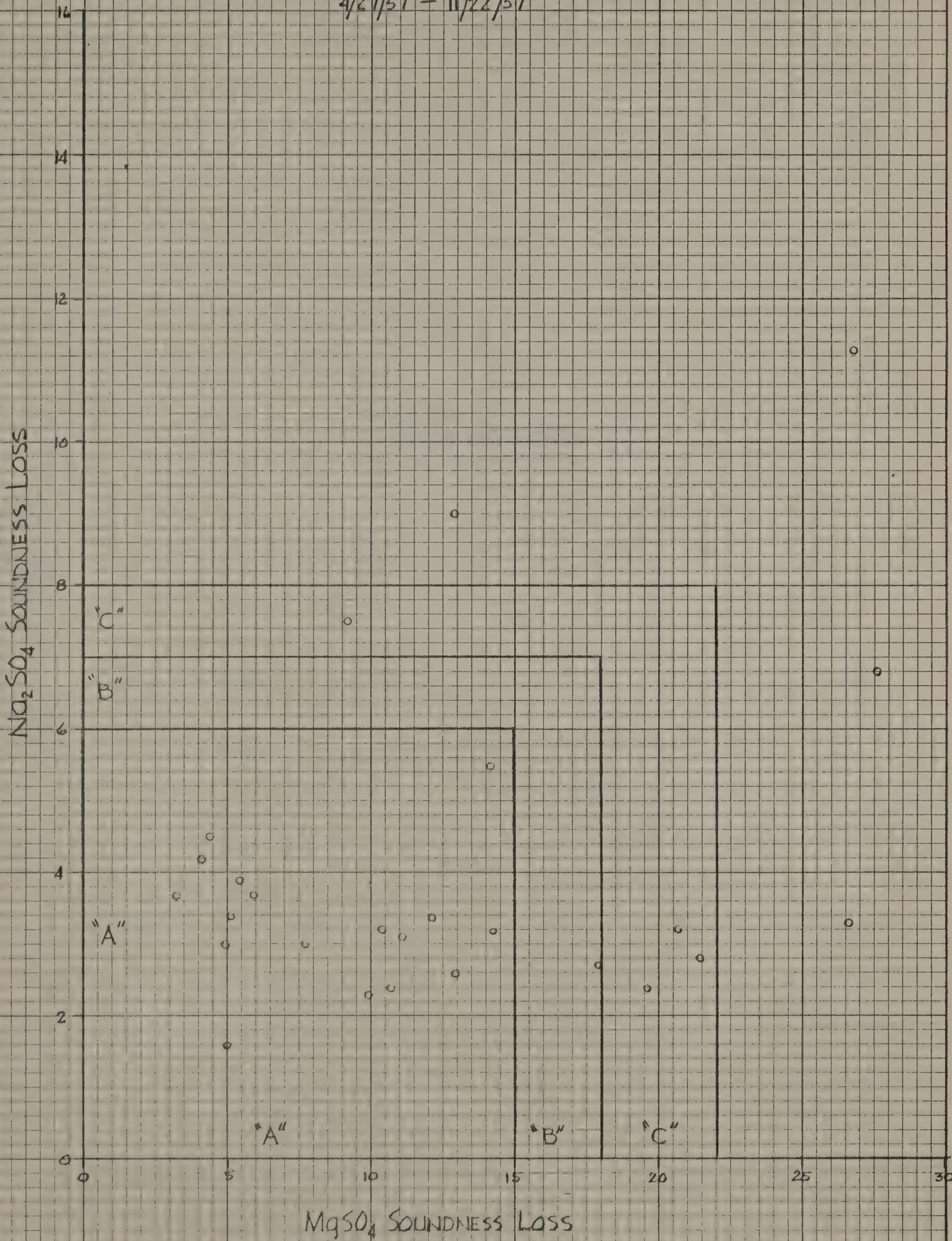


FIGURE 2(a)
CORRELATION OF $MgSO_4$ & Na_2SO_4
SOUNDNESS LOSSES
1/1/51 – 4/26/57
Na_2SO_4 Soundness Loss
$MgSO_4$ Soundness Loss
0
2
4
6
8
10
12
5
10
15
20
25
30
35
40
"A"
"B"
"C"

FIGURE 2(b)

CORRELATION OF $MgSO_4$ & Na_2SO_4 SOUNDNESS LOSSES

4/27/57 – 11/22/57



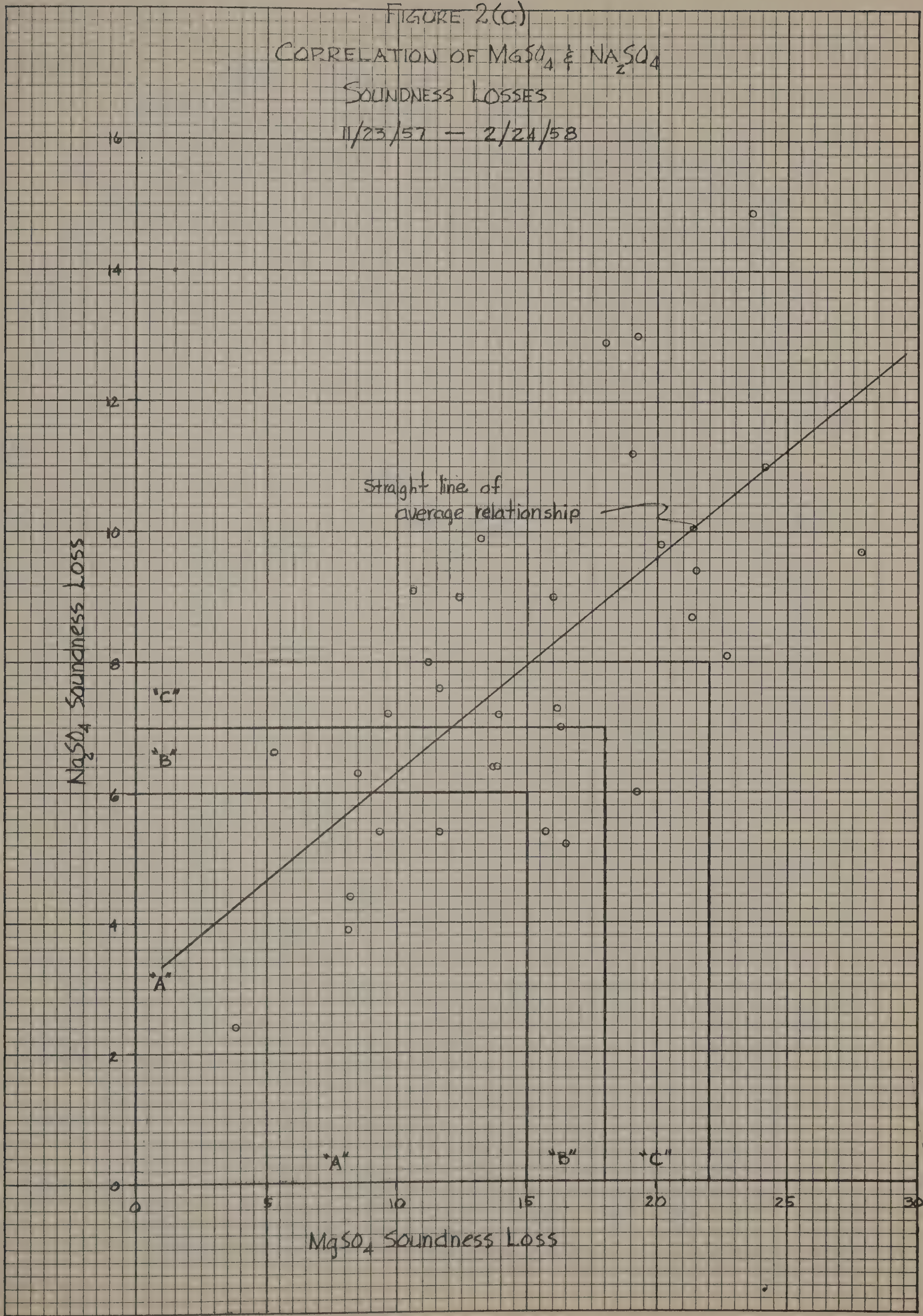


FIGURE 2(C)
CORRELATION OF $MgSO_4$ & Na_2SO_4
SOUNDNESS LOSSES
11/23/57 — 2/24/58
Straight line of
average relationship
Na_2SO_4 Soundness Loss
$MgSO_4$ Soundness Loss
"A"
"B"
"C"
0
2
4
6
8
10
12
14
16
5
15
20
25
30

FIGURE 2(d)

CORRELATION OF $MgSO_4$ & Na_2SO_4

SOUNDNESS LOSSES

2/25/58 — 8/14/59

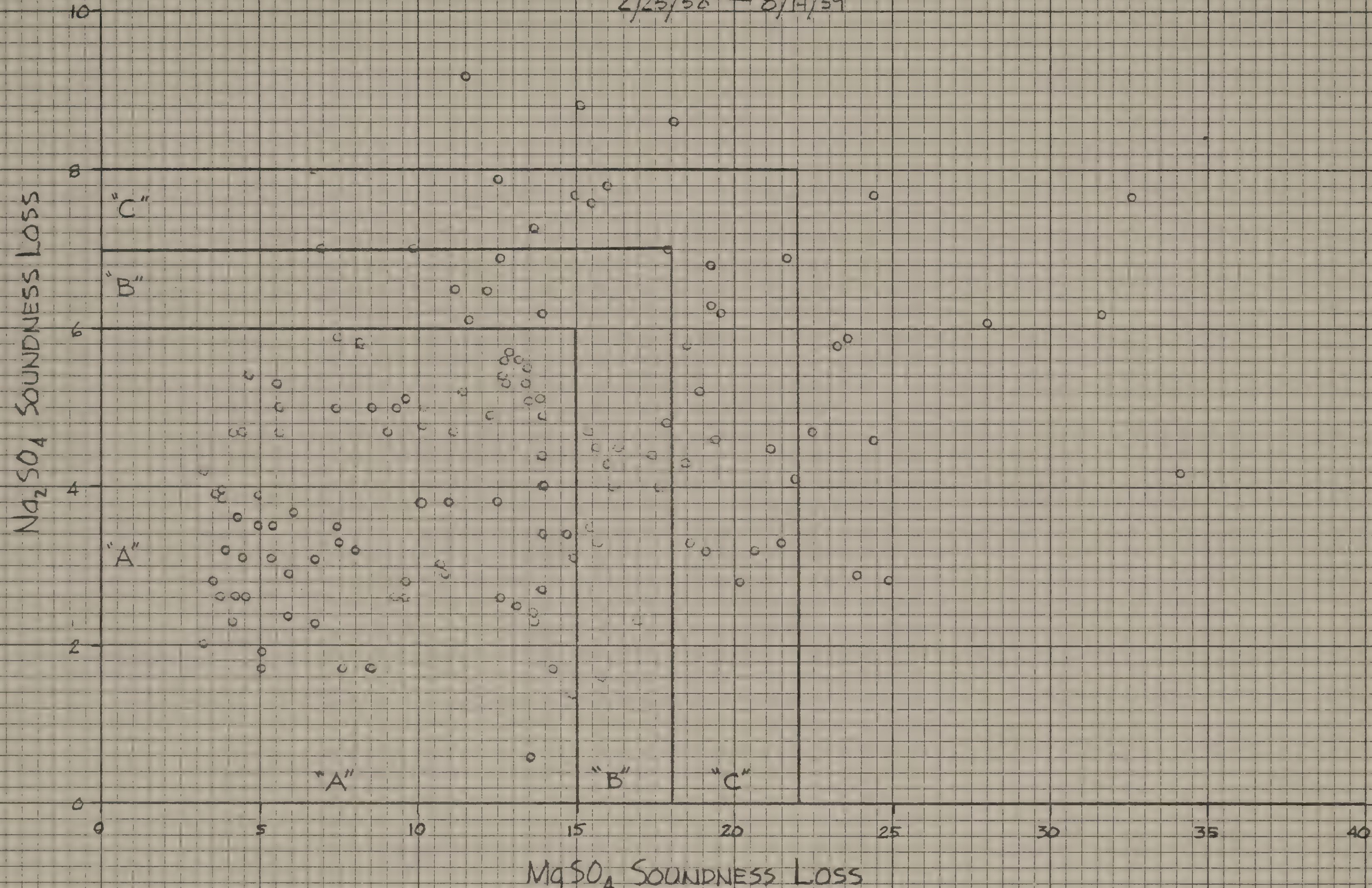
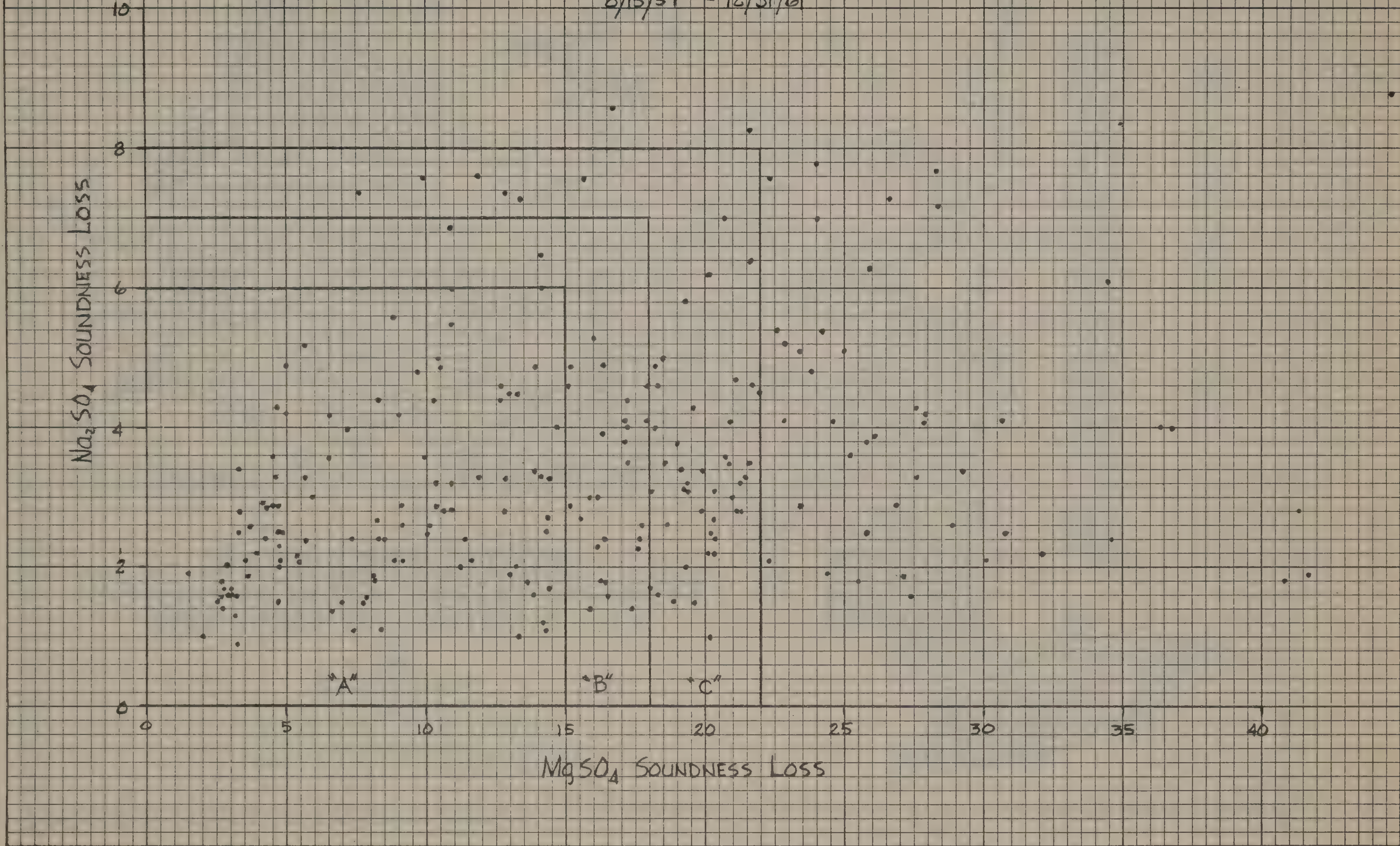


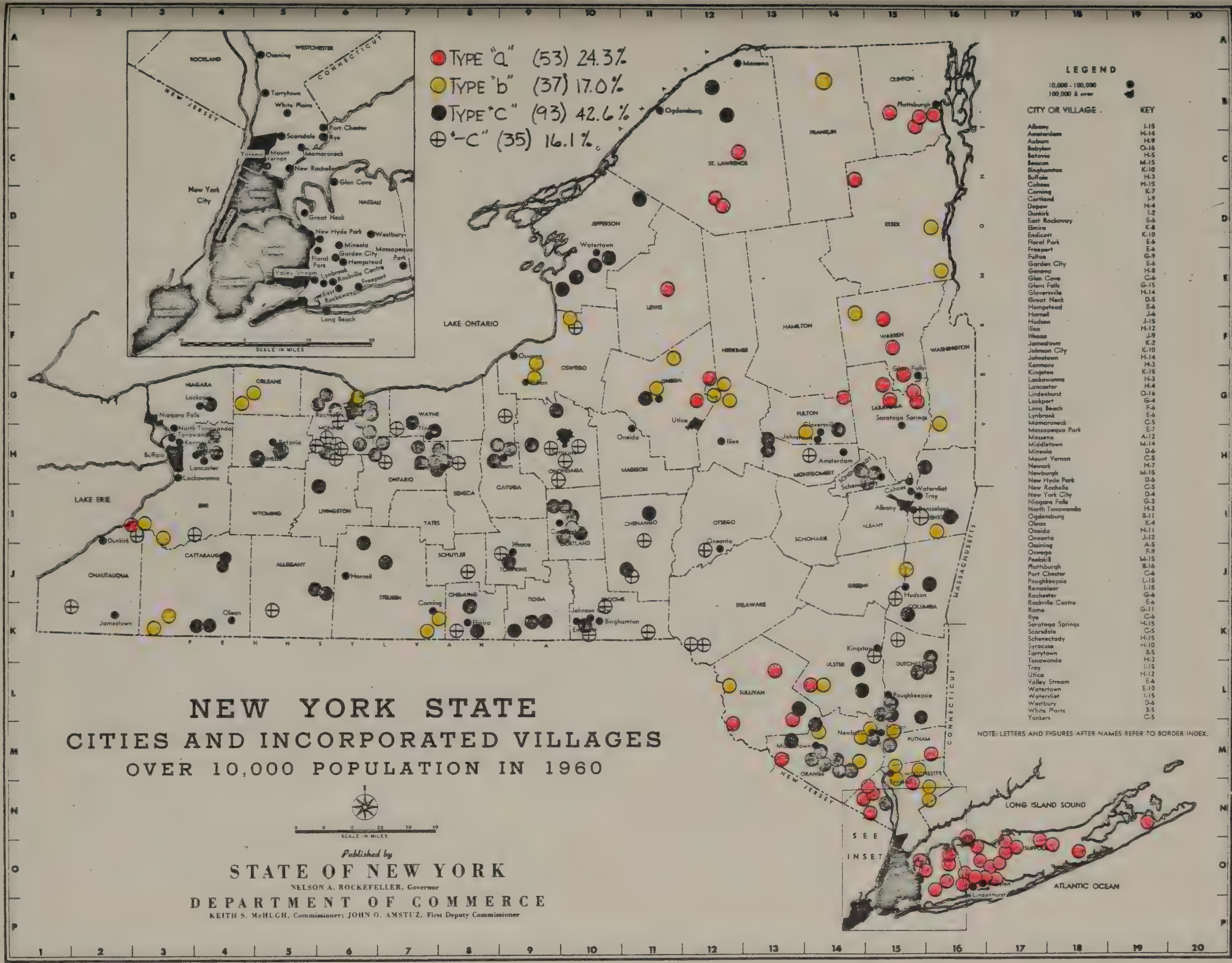
FIGURE 2 (e)

CORRELATION OF $MgSO_4$ & NA_2SO_4

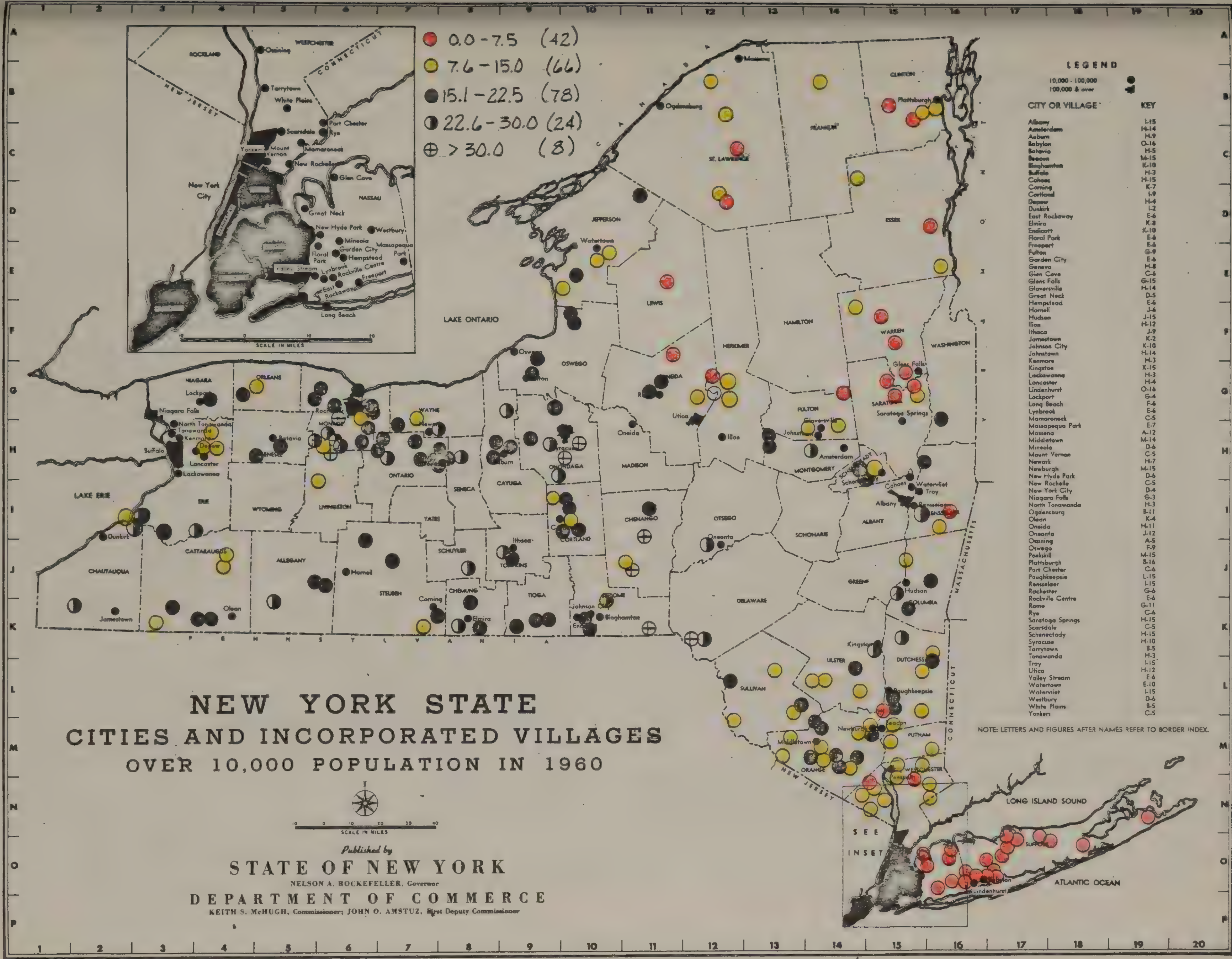
SOUNDNESS LOSSES

8/15/59 — 12/31/61

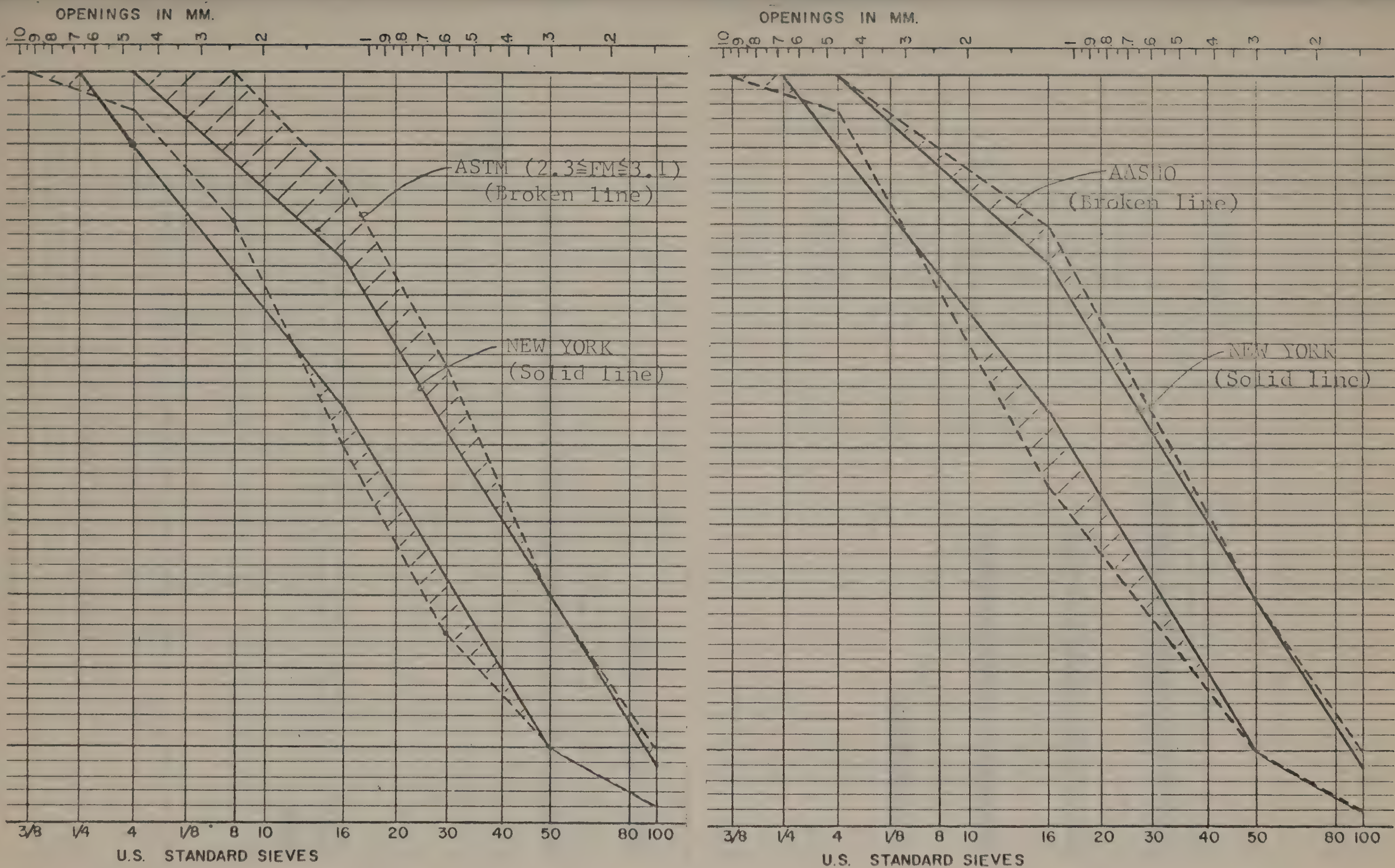




FINE AGGREGATE TYPE BASED ON AVERAGE PROPERTIES OF SAMPLES



AVE. LOSS BY $MgSO_4$ SOUNDNESS FOR NEW YORK FINE AGGREGATES



(a) (b)

FIGURE 5 - COMPARISON OF THE NEW YORK, ASTM & AASHO SPECIFICATIONS FOR GRADATION OF FINE AGGREGATE

FIGURE 6 - SUMMARY OF GRADATION VIOLATIONS

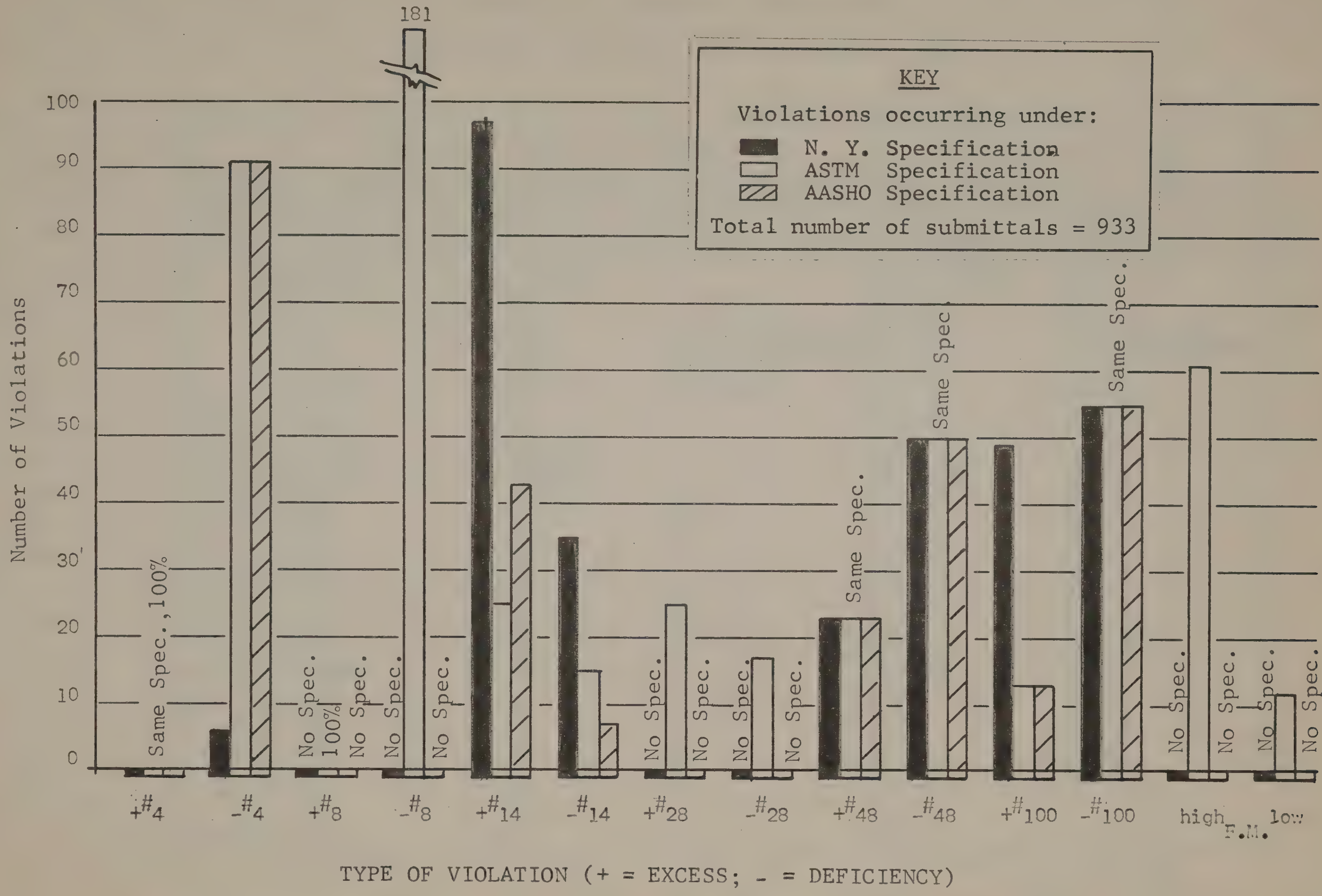
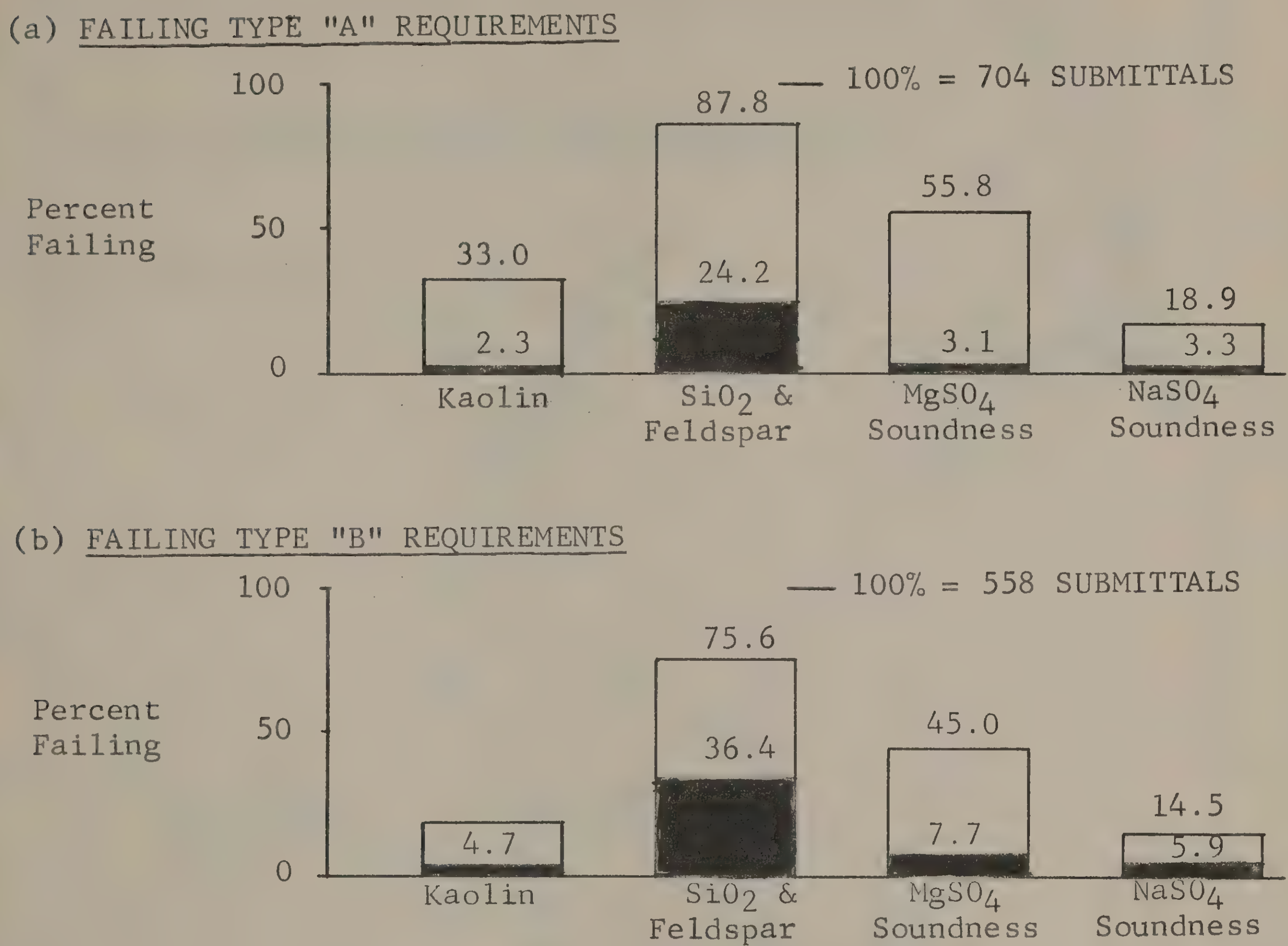


FIGURE 7 - FREQUENCY OF FAILURE BY
INDIVIDUAL TESTS AND COMBINATIONS OF TESTS

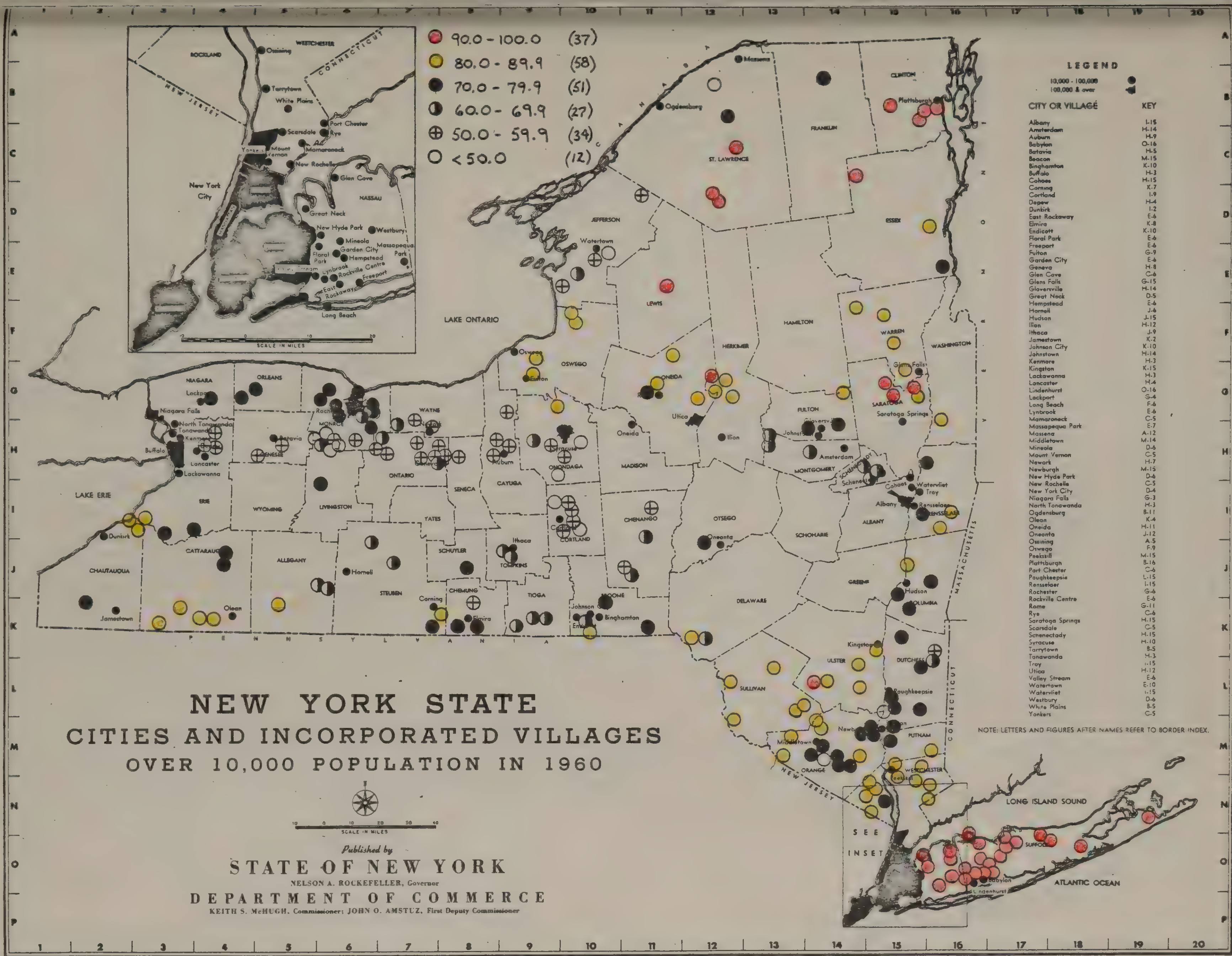
REQUIREMENT	NEW YORK STATE AS A WHOLE			DISTRICTS 6 & 9 ONLY	
	(a) FAILING TYPE "A" 0% – 70%	(b) FAILING TYPE "B" 0% – 70%	(c) FAILING TYPE "C" 0% – 70%	(d) FAILING TYPE "B" 0% – 70%	(e) FAILING TYPE "C" 0% – 90%
Q	24.2	36.4	-	35.4	-
K	2.3	4.7	-	2.1	-
M	3.1	7.7	69.9	9.4	88.5
N	3.3	5.9	19.6	0.0	0.0
Q & K	9.0	5.6	-	6.3	-
Q & M	24.0	21.2	-	21.9	-
Q & N	3.6	3.0	-	1.0	-
K & M	0.6	3.8	-	6.3	-
K & N	0.6	0.0	-	0.0	-
M & N	1.8	2.7	10.5	1.0	11.5
Q,K & M	17.6	5.7	-	13.5	-
Q,K & N	1.0	0.0	-	0.0	-
Q,M & N	6.5	3.0	-	1.0	-
K,M & N	0.1	0.2	-	0.0	-
Q, K, M&N	2.0	0.7	-	2.1	-
	100.0% = 704	100.0% = 558	100% = 133	100% = 96	100% = 26

Q = quartz & feldspar; K = kaolin; M = $MgSO_4$ soundness; N = $NaSO_4$ soundness

FIGURE 8 PERCENTAGE OF SUBMITTALS
FAILING REQUIREMENTS OF THE DIFFERENT AGGREGATE TYPES

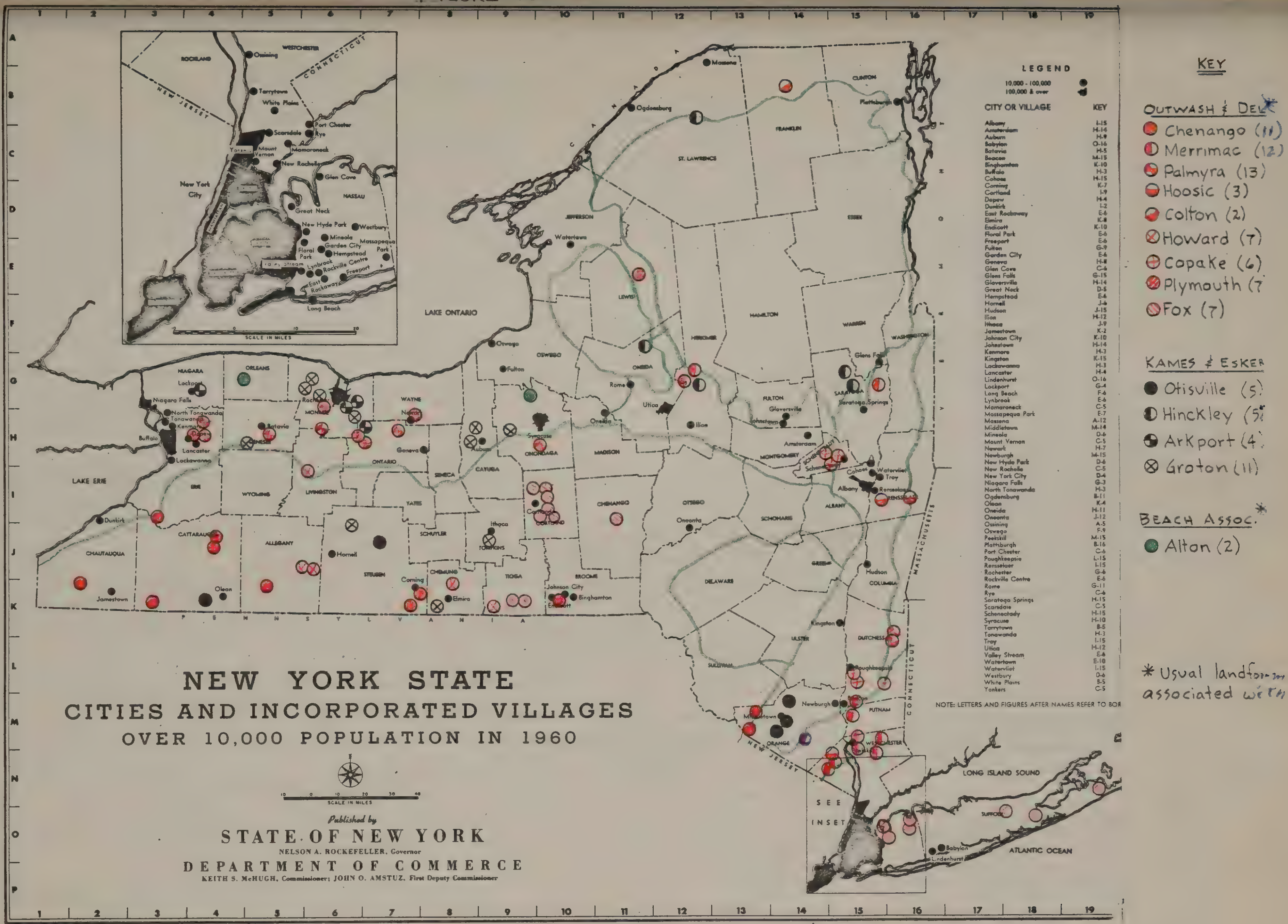


Darker portion of the bar indicates percentage of submittals unsatisfactory in the particular test alone.



AVE. TOTAL QUARTZ & FELDSPAR CONTENT OF NEW YORK FINE AGGREGATES

FIGURE 10



SOIL SERIES ASSOCIATION OF FINE AGGREGATE DEPOSITS

FIGURE 11 AVERAGE QUARTZ & FELDSPAR CONTENT OF DEPOSITS ASSOCIATED WITH THE SAME SOIL SERIES

SOIL SERIES NAME	Palmyra	Fox	Howard	Groton	Arkport	Copake	Hoosic	Chenango	Otisville	Alton	Hinckley	Merrimac	Colton	Plymouth
No. of Deposits	13	7	7	11	4	6	3	11	5	2	5	12	2	7
Among Deposit Mean	52.5	53.4	64.3	66.6	70.5	71.2	73.4	[illegible]	79.4	80.9	83.6	83.7	84.9	94.4

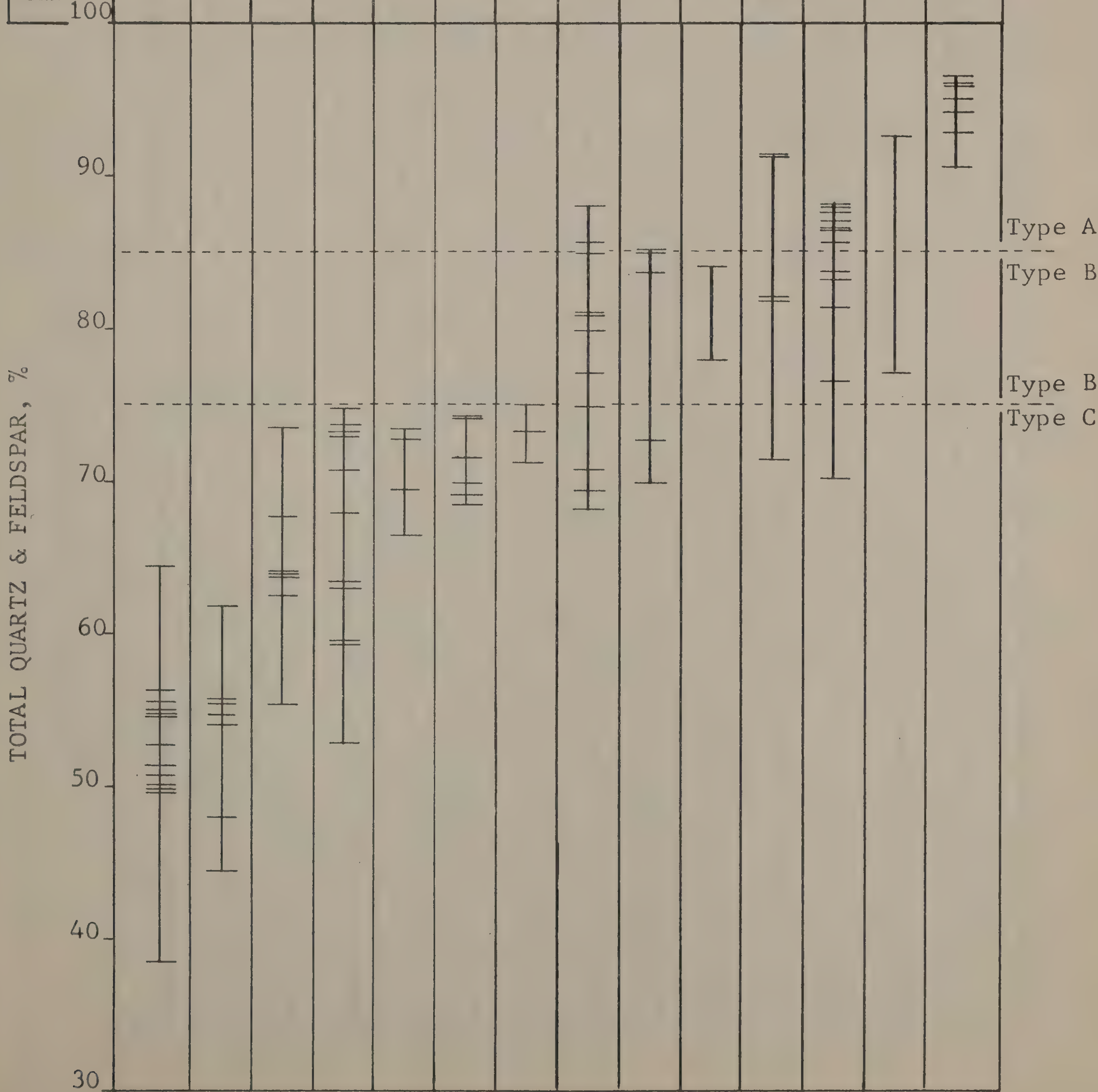


FIGURE 12 AVERAGE $MgSO_4$ SOUNDNESS OF DEPOSITS ASSOCIATED WITH THE SAME SOIL SERIES

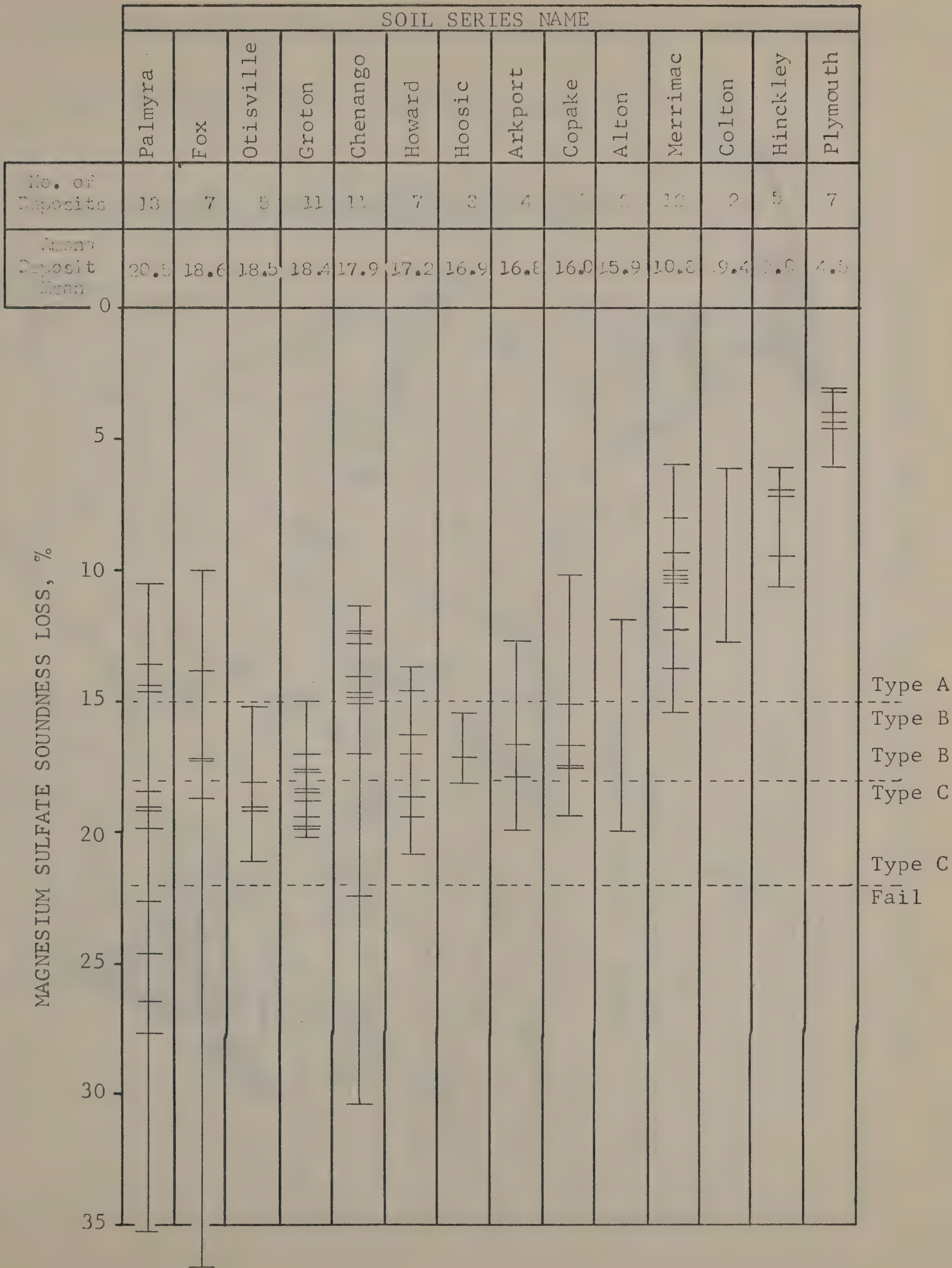
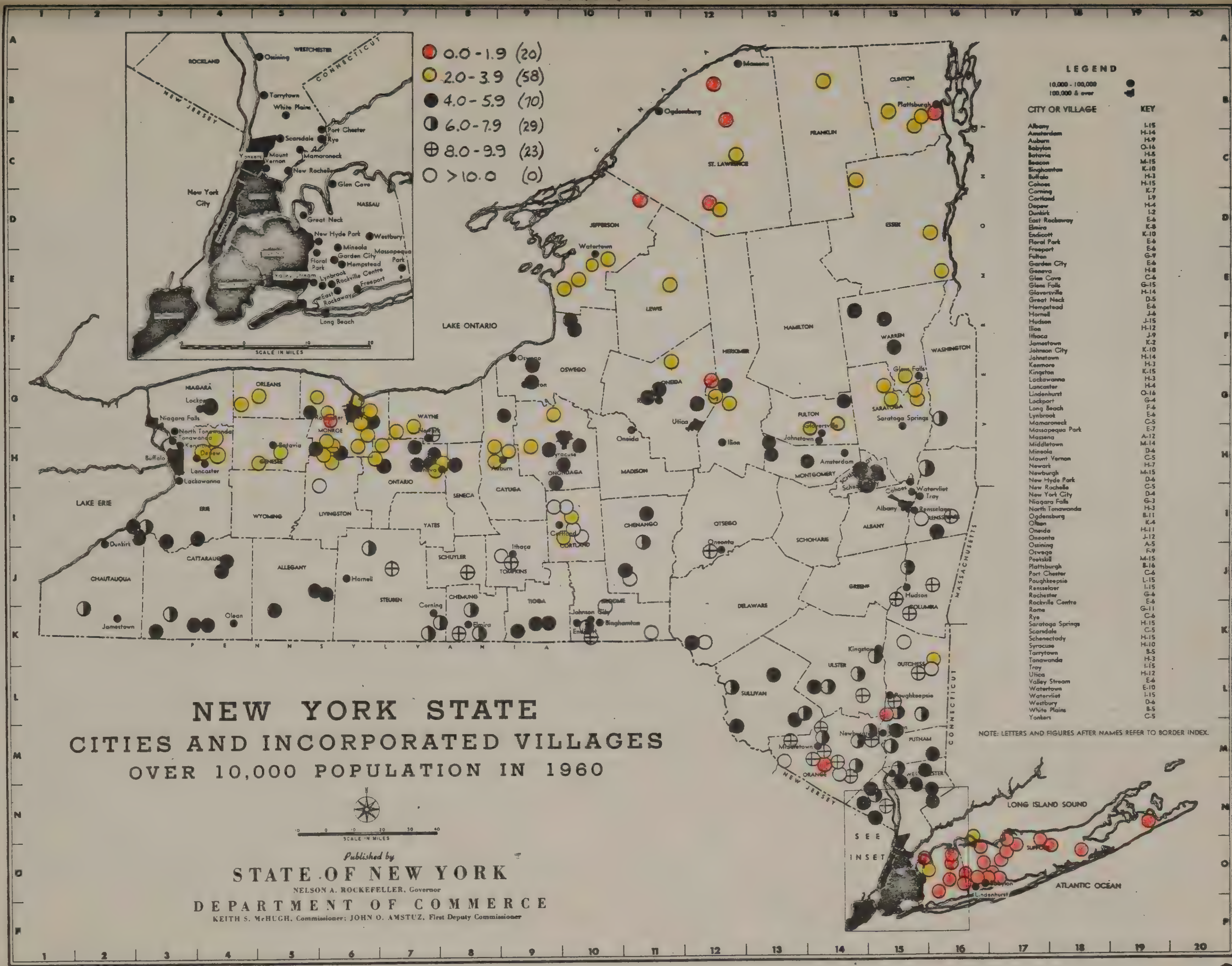


FIGURE 15



AVE. KAOLIN CONTENT OF NEW YORK FINE AGGREGATES

FIGURE 14 AVERAGE KAOLIN CONTENT
OF DEPOSITS ASSOCIATED WITH THE SAME SOIL SERIES

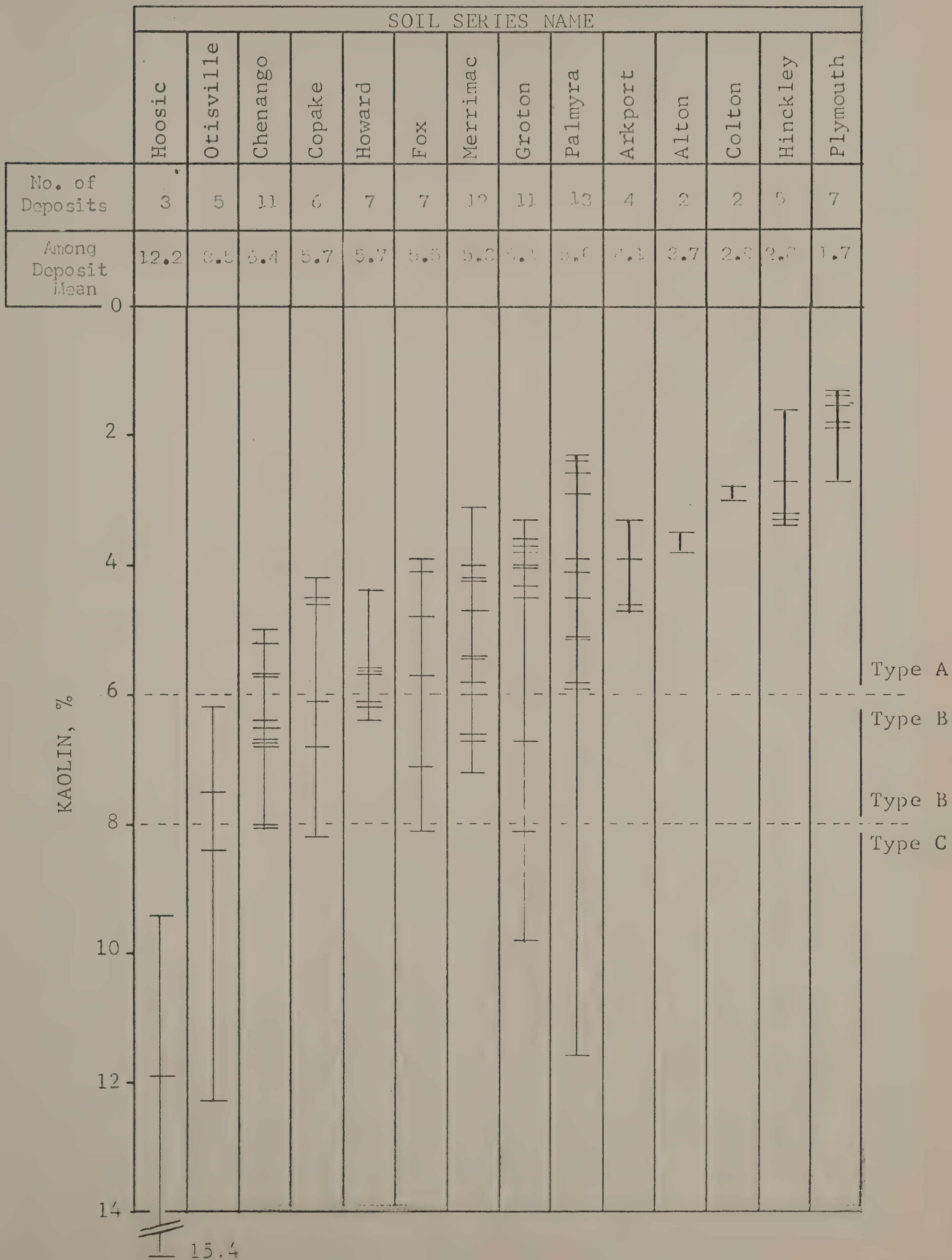
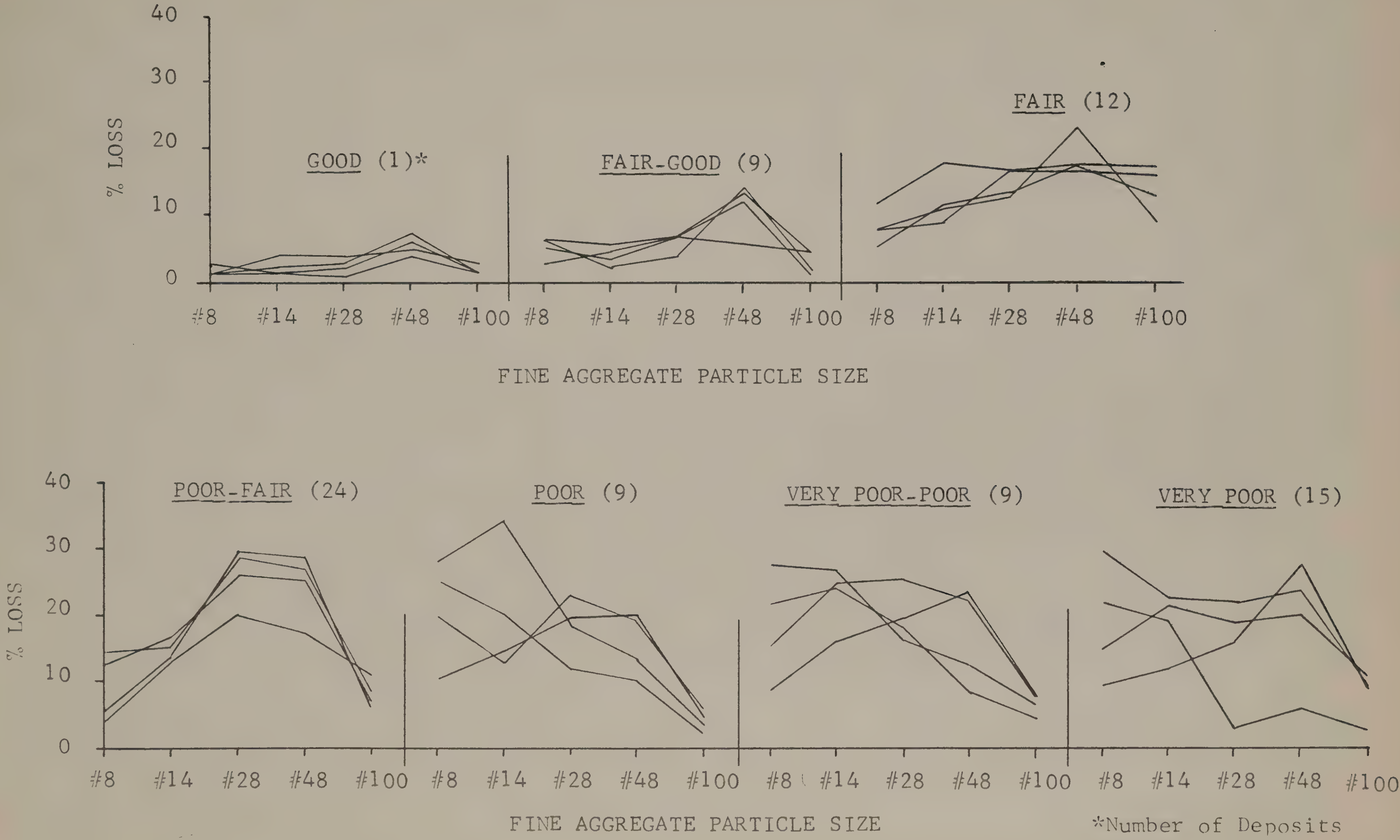


FIGURE 1[illegible] - TYPICAL EXAMPLES OF
EVALUATION OF WITHIN-DEPOSIT UNIFORMITY OF "SOUNDNESS-PARTICLE SIZE" RELATIONSHIP



*Number of Deposits so classified

TABLE 1 - FINE AGGREGATE REQUIREMENTS
OF NEW YORK STATE

	TYPE		
	a	b	c
Rational Analysis:			
Kaolin, Max. %	6	8	*
Quartz and Feldspar, Min. %	85	75	*
Soundness:			
10 Cycle Sodium Sulfate, Max. % Loss	6	7	8
5 Cycle Magnesium Sulfate, Max. % Loss	15	18	22

* No Requirement

TABLE 2

SUMMARY OF FINE AGGREGATE ACCEPTANCE TESTS BY YEAR

YEAR	FINE AGGREGATE TYPE								TOTAL TESTS FOR YEAR
	TYPE "A"		TYPE "B"		TYPE "C"		FAILING		
	No. FOR YEAR	% FOR YEAR	No. FOR YEAR	% FOR YEAR	No. FOR YEAR	% FOR YEAR	No. FOR YEAR	% FOR YEAR	
1951	14	21.6	11	16.9	36	55.5	4	6.2	65
1952	9	18.3	12	24.5	21	42.9	7	14.3	49
1953	19	15.8	29	24.1	65	54.1	7	5.8	120
1954	23	25.3	16	17.6	42	46.2	10	11.0	91
1955	21	25.6	16	19.5	37	45.2	8	9.8	82
1956	23	27.1	11	12.9	39	45.9	12	14.1	85
1957	20	26.0	11	14.3	26	33.8	20	26.0	77
1958	26	26.2	15	15.2	45	45.4	13	13.1	99
1959	28	29.8	7	7.5	46	49.0	13	13.8	94
1960	24	27.2	9	10.2	35	39.8	20	22.7	88
1961	22	26.5	9	10.8	33	39.8	19	22.9	83
TOTAL FOR 11 YEARS	229	-	146	-	425	-	133	-	933
% FOR 11 YEARS	-	24.5	-	15.7	-	45.6	-	14.3	-

TABLE 3 - PERIODS OF DIFFERENT SOLUTION CONCENTRATION IN THE SODIUM SULFATE SOUNDNESS TEST

Period	Tests	Sp.Gr.of Solution	Total Tests	Total Failures	Number Failing Mg Alone	Na Alone	Both
1/1/51-4/26/57	51-F-2 thru 57-F-30	1.160	505	48	33	9	6
4/27/57-11/22/57	57-F-31 " 57-F-84	1.180	28	6	4	1	1
11/23/57-2/24/58	57-F-85 " 57-F-118	1.195	32	14	0	9	5
2/25/58-8/14/59	57-F-119 " 59-F-60	1.160	135	16	11	4	1
8/15/59-12/31/61	59-F-60 " 61-F-185	1.180	233	49	45	2	2
		TOTALS:	933	133	93	25	15

TABLE NO. 4

ANALYSIS OF TEST ASSOCIATIONS

TEST COMBINATIONS	(P) PREDICTED OCCURRENCE	(A) ACTUAL OCCURRENCE	[A-P]	SIGNIFICANT @ 0.05% LEVEL	RATIO: A/P
		SUBMITTALS FAILING "A" REQUIREMENTS			
Quartz-Felds. & Kaolin	0.166	0.223	0.057	Yes	1.34
Quartz-Felds & $MgSO_4$	0.279	0.382	0.103	Yes	1.37
Quartz-Felds. & Na_2SO_4	0.096	0.099	0.003	No	-
Kaolin & $MgSO_4$	0.105	0.153	0.048	Yes	1.46
Kaolin & Na_2SO_4	0.037	0.028	0.009	No	-
$MgSO_4$ & Na_2SO_4	0.061	0.079	0.018	No	-
		SUBMITTALS FAILING "B" REQUIREMENTS			
Quartz-Felds. & Kaolin	0.056	0.072	0.016	No	-
Quartz-Felds. & $MgSO_4$	0.121	0.183	0.062	Yes	1.51
Quartz-Felds. & Na_2SO_4	0.039	0.041	0.002	No	-
Kaolin & $MgSO_4$	0.034	0.062	0.028	Yes	1.82
Kaolin & Na_2SO_4	0.011	0.016	0.005	No	-
$MgSO_4$ & Na_2SO_4	0.023	0.040	0.017	Yes	1.74
		SUBMITTALS FAILING "C" REQUIREMENTS			
$MgSO_4$ & Na_2SO_4	0.002	0.018	0.016	Yes	9.00

TABLE NO. 5

RELATIONSHIP BETWEEN PEDOLOGICAL SOIL SERIES NAME OF DEPOSIT AND QUARTZ AND FELDSPAR CONTENT OF AGGREGATE

PEDOLOGICAL SOIL SERIES NAME	AMONG DEPOSIT VARIATION IN MEANS			TOTAL SAMPLES FROM SOIL TYPE		
	NUMBER OF DEPOSITS	STAT. SIGNIF. AT 0.5% LEVEL	PRACTICAL SIGNIFICANCE	NUMBER OF SAMPLES	ARITHMETIC MEAN	STANDARD DEVIATION
Palmyra	13	Yes		71	51.8	4.5
Fox	7	No	None { 17 samples from 1 deposit; 4 from another; 7 from remaining 5	28	54.7	5.9
Howard	7	Yes	-	62	64.2	8.6
Groton	11	Yes	-	96	65.4	8.6
Copake	6	No	Limited - limited geo. distribution	31	70.5	3.1
Arkport	4	No	Limited - too few deposits	24	72.1	5.5
Hoosic	3	No	Limited - too few deposits & limited geo. distribution	23	73.1	4.3
Chenango	11	Yes	-	103	77.6	7.8
Alton	2	Yes	-	19	77.8	3.1
Otisville	5	Yes	-	47	79.8	6.8
Hinckley	5	Yes	-	34	82.8	8.2
Colton	2	Yes	-	20	83.4	8.0
Merrimac	12	Yes	-	66	84.9	4.7
Plymouth	7	No	None { All deposits are on L. I. where all Materials are similar			

TABLE NO. 6

RELATIONSHIP BETWEEN PEDOLOGICAL SOIL SERIES NAME OF DEPOSIT AND MAGNESIUM SULFATE SOUNDNESS OF AGGREGATE

PEDOLOGICAL SOIL SERIES NAME	AMONG DEPOSIT VARIATION IN MEANS			TOTAL SAMPLES FROM SOIL TYPE		
	NUMBER OF DEPOSITS	STAT. SIGNIF. AT 0.05% LEVEL	PRACTICAL SIGNIFICANCE	NUMBER OF SAMPLES	ARITHMETIC MEAN	STANDARD DEVIATION
Plymouth	7	No	None { All deposits on L.I. where all mat'ls. are similar	27	4.7	1.6
Hinckley	5	Yes	-	33	7.6	2.3
Colton	2	No	None — One deposit appears to be miss-mapped	19	9.8	25.5
Merrimac	12	Yes	-	65	10.7	3.8
Alton	2	Yes	-	18	13.2	3.9
Chenango	11	Yes	-	99	14.2	5.4
Copake	6	No	Limited — limited geo. distribution	30	15.8	3.9
Hoosic	3	No	Limited — too few deposits	23	16.6	4.4
Howard	7	No	Satisfactory	61	16.7	4.8
Arkport	4	No	Limited — too few deposits	23	17.3	3.3
Fox	7	No	None — 17 samples from 1 deposit, 4 from another, 7 from remaining 5	27	18.0	6.3
Groton	11	No	Satisfactory	95	18.1	4.1
Otisville	5	No	Limited — too few deposits	47	18.3	4.6
Palmyra	13	Yes	-	68	18.6	5.9

TABLE NO. 7

RELATIONSHIP BETWEEN PEDOLOGICAL SOIL SERIES NAME OF DEPOSIT AND KAOLIN CONTENT OF AGGREGATE

PEDOLOGICAL SOIL SERIES NAME	AMONG DEPOSIT VARIATION IN MEANS			TOTAL SAMPLES FROM SOIL TYPE		
	NUMBER OF DEPOSITS	STAT. SIGNIF. AT 0.05% LEVEL	PRACTICAL SIGNIFICANCE	NUMBER OF SAMPLES	ARITHMETIC MEAN	STANDARD DEVIATION
Plymouth	7	No	None { All deposits on L.I. where all mat'ls. are similar	28	1.9	0.9
Hinckley	5	Yes	-	34	2.7	0.9
Colton	2	No	None — too few deposits	20	2.9	1.5
Alton	2	No	None — too few deposits	19	3.8	1.6
Palmyra	13	Yes	-	70	4.2	2.8
Arkport	4	No	Limited — too few deposits	24	4.5	1.3
Fox	7	Yes	-	28	4.8	1.2
Merrimac	12	Yes	-	66	5.1	1.6
Groton	11	Yes	-	96	5.3	3.0
Copake	6	Yes	-	31	5.3	1.9
Howard	7	No	Satisfactory	62	5.7	1.5
Chenango	11	Yes	-	102	6.7	1.9
Otisville	5	No	Limited — too few deposits	47	7.6	3.3
Hoosic	3	No	Limited - too few dpsts. & limited geo.distr.	23	11.0	4.2

TABLE NO. 8

NUMBER OF OCCURRENCES OF WITHIN-DEPOSIT LOSSES
FALLING WITHIN SPECIFIED RANGES

NUMBER OF SAMPLES PER DEPOSIT	#8 SIZE				#14 SIZE				#28 SIZE				#48 SIZE				#100 SIZE			
	0 ≤ 4	>4 ≤ 8	>8 ≤ 12	>12	0 ≤ 4	>4 ≤ 8	>8 ≤ 12	>12	0 ≤ 4	>4 ≤ 8	>8 ≤ 12	>12	0 ≤ 4	>4 ≤ 8	>8 ≤ 12	>12	0 ≤ 4	>4 ≤ 8	>8 ≤ 12	>12
2	2	7	3	4	5	4	3	4	8	3	3	2	7	7	1	1	13	2	0	1
3	3	4	6	6	6	4	4	5	5	6	4	4	4	7	3	5	8	7	2	2
4	1	5	7	10	4	2	8	9	5	7	6	5	3	4	9	7	6	10	7	0
5	0	1	1	8	0	0	2	8	0	5	3	2	0	4	2	4	0	7	2	1
6	0	1	1	7	0	1	0	8	0	1	0	8	0	0	3	6	0	2	1	6
7	0	0	0	2	0	0	0	2	0	0	1	1	0	0	0	2	0	0	0	2
TOTALS	6	10	18	37	15	11	17	36	18	22	17	22	14	22	18	25	27	28	12	12
3 (Lab. Sample)	7	3	2	0	6	4	1	1	10	2	0	0	11	1	0	0	9	3	0	0
6 (Lab. Sample)	2	2	1	1	1	4	1	1	4	2	0	0	3	2	1	0	2	3	0	1